PIONEER VENUS

Proceedings of the Pioneer Venus Science Steering Group

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035

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March – June 1972

PROCEEDINGS OF THE PIONEER VENUS SCIENCE STEERING GROUP

(MARCH - JUNE, 1972)

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PROCEEDINGS OF THE PIONEER VENUS SCIENCE STEERING GROUP

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242-1:PS-VP-2-08 February 1, 1972

To: NASA Headquarters
Attention: Dr. Robert F. Fellows, Code SL

From: L. Colin, Project Scientist

Subject: Preliminary Working Plan for the Venus-Pioneer Mission Definition Group (MDG)

As promised, we have developed a preliminary working plan for the Venus-Pioneer Mission Definition Group (MDG). The plan is contained in enclosure 1, Venus-Pioneer MDG Goals and Objectives, and enclosure 2, Venus-Pioneer MDG Preliminary Agenda. A flexible time schedule is of course important. However, to ensure adequate coverage and reiteration of the MDG goals and objectives, we have divided the four month period, March 1 - July 1, into the 5 meetings as shown. The first is a 2-day meeting at GSFC in early March. The subsequent meeting would be 3 days in duration. Due to strong interaction required of the MDG and Venus-Pioneer Project personnel, we strongly advocate that the second, third and fourth meetings all be held at Ames. The last meeting should be held at Headquarters.

We are prepared to handle the minutes of each meeting, including recording, typing and dissemination. We are also prepared to write and publish the final report.

I would appreciate your comments on these matters and I am sending a copy of this correspondence to Dr. Bauer, GSFC, for similar comments.

Lawrence Colin

Enc. 1. Venus-Pioneer MDG Prel. Plan
2. Venus-Pioneer MDG Prel. Agenda

cc: Dr. S. Bauer, GSFC, Code 620

NASA - Ames

VENUS-PIONEER MISSION DEFINITION GROUP

GOALS AND OBJECTIVES

1. SCIENTIFIC OBJECTIVES OF VENUS EXPLORATION - A review and up-dating, as required, of the scientific objectives of Venus exploration, established by the 1970 NAS/Space Science Board Study, in light of subsequent scientific findings concerning Venus.

2. EXPLORATION STRATEGY - A review and up-dating, as required, of the exploration strategy established by the NAS-SSB considering: (a) the basic scientific objectives, (b) new launch dates - 76/77, 78, 80 and (c) Venus-Pioneer program concepts and constraints. Establishment of criteria for probe targeting and dispersion, orbital parameters, tracking requirements, etc.

3. SCIENCE MEASURABLES - Enumeration and prioritization of baseline scientific measurables based on scientific objectives of Venus exploration and the exploration strategy. Measurement criteria will be established including sampling locations and rates, precision, accuracy, dynamic range, frequency range, etc.

4. SCIENCE PAYLOADS - Enumeration and prioritization of scientific instrument payloads considering the scientific objectives of Venus exploration, exploration strategy, science measurables and Venus-Pioneer concept. Payloads will be determined for the bus, large probe and mini-probes for the 76/77 dual-probe mission and for the 78 mission. Instrument and S/C interface requirements will be determined.

5. LONG-LEAD TERM INSTRUMENT DEVELOPMENT - Identification of critical, non-proven flight instruments, considering the scientific payloads outlined above, to be provided project development support prior to AFO release. Also, identification of possible scientific instrumentation which should be project-supplied.

6. MODEL ATMOSPHERE - Selection of a model atmosphere, or environment, for Venus to be used for engineering purpose and communications system design.

7. ARECIBO CONSIDERATIONS - Assessment of the importance of the use of an upgraded Arecibo facility complex as a back-up to the DSN for the purpose of enhancing data transmission rates.

8. SUPPORTING RESEARCH - Identification of desirable NASA-supported laboratory, ground-based, airborne measurements.

Encl. 1

9. 1980 MISSION - Preliminary considerations of alternatives for the 1980 mission considering overall exploration strategy and anticipated results for the 76/77 and 78 missions.

10. FINAL REPORT - Preparation of a Mission Definition Group (MDG) Final Report to serve as the Venus-Pioneer Mission Definition Plan, Criteria document for Phase B studies and for preparation of an AFO.

1.

NASA - Ames

VENUS-PIONEER MISSION DEFINITION GROUP

PRELIMINARY AGENDA

Meeting No. 1 - March 1, 2

I.	Introductory Remarks	NASA Headquarters Dr. R. Fellows & D. Herman
II.	Planetary Explorer Historical Summary	NASA Goddard Space Flight Center S. Bauer
III.	MDG Order of Business, Goals, Agenda	NASA Ames Research Center L. Colin
IV.	Preliminary Discussions:	
a.	Scientific objectives of Venus Exploration	MDG
b.	Exploration Strategy	MDG
c.	Science Measurables	MDG
d.	Science Payloads	MDG

Meeting No. 2 - Week of March 27

I.	Venus Pioneer Orientation	
a.	Project Plan and Philosophy	NASA Ames Research Center B. D. Padrick
b.	Systems Design Parameters, Constraints	NASA Ames Research Center J. Sperans
c.	Preliminary Mission Analyses, Trade-offs	NASA Ames Research Center R. Jackson
d.	Current Scientific Instrument Status	NASA Ames Research Center J. Sperans
e.	Current Spacecraft Design Status	NASA Ames Research Center R. Christiansen
f.	Current Entry Probe Status	NASA Ames Research Center T. Canning
II.	Preliminary Discussions	
a.	Long Lead Term Instrument Development	MDG
b.	Model Atmosphere	MDG

Enc 2.

Meeting No. 3 - Week of May 1

I.	Detailed Mission Trade-offs	Ames Research Center R. Jackson
II.	Detailed Payload Trade-offs	Ames Research Center J. Sperans
III.	Tracking Considerations	Ames Research Center T. Grant
IV.	Data Transmission Considerations	Ames Research Center T. Grant
V.	Detailed Discussions	
	a. Long-Lead Term Instrument Development	MDG
	b. Model Atmosphere	MDG
VI.	Preliminary Discussions	
	a. Arecibo Considerations	MDG
	b. Supporting Research	MDG
	c. 1980 Mission	MDG

Meeting No. 4 - Week of May 29

I.	Detailed Discussions	
	a. Arecibo Considerations	MDG
	b. Supporting Research	MDG
	c. 1980 Mission	MDG
II.	Preliminary Discussions	
	a. Final Report	MDG
III.	Venus-Project Presentations as Needed	

Meeting No. 5 - Week of June 26

I.	MDG Conclusions and Recommendations	MDG
II.	Final Presentations	Venus-Project Personnel
III.	Preparation of Final Reports	MDG

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

MAR 2 1 1972

REPLY TO
ATTN OF: SL(RFF:rab)

SUMMARY MINUTES:	**PIONEER VENUS SCIENCE STEERING GROUP (MEETING NO. 1)**
DATE:	March 7 and 8, 1972
TIME:	9:00 am (March 7) - 3:45 pm (March 8)
PLACE:	Goddard Space Flight Center Greenbelt, Maryland

PRESENT:

Chairman:	R. Fellows
Co-Chairmen:	S. Bauer L. Colin
Members:	S. Blamont J. Gille R. Goody D. Hunten A. Kliore A. Nagy G. Pettengill C. Russell A. Seiff I. Shapiro N. Spencer U. Von Zahn J. Weinman
Project Staff:	R. Jackson J. Sperans
NASA Hqtrs:	D. Herman R. Kraemer I. Rasool H. Smith
Invited Guests:	G. Levin P. Marcotte

ORIGINAL PAGE IS
OF POOR QUALITY

I. SUMMARY MINUTES:

The meeting started with brief introductions of all attendees. Mr. Robert Kraemer, Director of Planetary Programs, described the history of the planning for probe missions to Venus and the manpower and resources problems which made it necessary to transfer Project responsibility from the Goddard Space Flight Center to the Ames Research Center. At that time the project name was changed from Planetary Explorer to Pioneer Venus. It is planned that Pioneer Venus will be a budget start in the FY-74 budget. Until then funding will be accomplished under advanced development funds.

Mr. Daniel Herman, Manager of Advanced Programs and Technology and Acting Program Manager for the Pioneer Venus Project, described the schedule status of the program. He announced that the Request for Proposals (RFP) was about to be released momentarily (it was released March 8) and that at least three bids were expected. He also discussed the question of possible conflict of interest in relation to members of the group carrying out consultative arrangements with possible bidders or having other contacts which at a later date may be viewed as having given unfair advantage to one prospective bidder over others.

The history of the Planetary Explorer study phase by Goddard Space Flight Center and the results were summarized by Dr. Bauer. The current status of Pioneer Venus planning was described by Dr. Colin, Mr. Sperans, and Mr. Jackson. Following release of the RFP, a briefing to bidders is scheduled at Ames Research Center for 16 March. Proposals will be due 1 May. Nine month phase B study contracts are expected to be awarded to two bidders by 1 October 1972.

The Chairman summarized the responsibilities and objectives of the Science Steering Group (SSG) as: (1) Defining a typical payload for the first probe mission (76-77); (2) Recommending strategy and objectives for the orbiter and/or probe missions for the 1978 and 1980 opportunities; and (3) Identification of long-lead time and critical experiment development items and necessary supporting research for the missions. The Chairman further commented that while this appeared to be a major undertaking in view of the schedule which called for dissolution of the SSG by 1 July 1972, he felt it could be done because of the large amount of preliminary planning already performed and the availability of the National Academy of Sciences June 1970 report on strategy for the exploration of Venus.

The Chairman further reported that the science schedule called for release of the Announcement of Flight Opportunity (AFO) for experiments shortly after 1 July 1972, with evaluations to be in late Fall and selection of experiments for the 1976-77 probe mission by 1 January 1973.

The subject of possible conflict of interest involving the members of the SSG was discussed in detail and the following rules suggested as an interim procedure by the Chairman and the Project Staff representatives: (1) No member should carry out any type of consultative role with prospective bidders for the Phase B study contract during the formal existance of the SSG. (2) Any contacts between SSG members and bidders would be through the Ames Project Staff (Dr. L. Colin) and then only under such circumstances as to afford to all bidders the equal opportunity for access to the information disclosed.

The majority of the time of this two day meeting was devoted to detailed discussions of probe experiments and instruments contained in the June 1970 Venus report. Also included were discussions of the role of earth based radio and radar techniques applicable to the missions. As a result of possible problems and the need for additional information disclosed by the discussions the following organization by subgroups was arranged to prepare for the next meeting:

(1) Cloud Experiments: Gille, Weinman

(2) Atmospheric Structure: Hunten, Von Zahn, Nagy, Kliore, Shapiro, Seiff, Spencer, Bauer

(3) Miniprobe: Goody, Blamont, Pettengill, Russell

(Name of group leader is underlined).

Dr. Rasool, Deputy Director for Planetary Programs, commented on several points following the discussion. He urged the SSG to do a realistic job in defining the experiments, the instruments to make the measurements, and the practicality of the instrument interface with the spacecraft and the environment. He stressed that recognition of the problems involved and their successful solution early in planning would decrease the likelihood of the necessity of making painful decisions leading to dropping of experiments at a later date when the project would be in the hardware and fabrication stage. He also stated that two very important areas for further examination were the potential and implementation of very long baseline interferometry and the practicality of mass spectrometric measurements in the lower atmosphere.

II. ACTION ITEMS:

The following items were identified as requiring further information or action.

1. Conflict-of-interest considerations. (Fellows, Colin)
2. Arecibo--possible role for 76/77 probe mission. (Fellows)
3. SSG request for briefing on Mariner Venus '73 mission. (Fellows)

4. Obtain contents or summary of Donahue Space Science Board Study on Venera missions to Venus. (Fellows)

5. Report on use of Very Long Baseline Interferometry techniques in conjunction with probe mission. (Pettengill, Shapiro)

6. Report on "geoscience" implications of magnetometer experiments from orbiter and spacecraft. (Russell)

7. Report on use and value of magnetometers in atmospheric probes. (Russell)

8. Report on present status of mass spectrometry for main probe experiments, i.e. present capability, development needs, work underway, etc. (Spencer)

9. It was recommended that Leovy, Lewis, and Donahue be contacted as to their interest in participating at a future meeting as consultants. (Fellows)

10. The project staff will identify possible candidate experiments for consideration by the SSG. (Colin)

11. The project staff will obtain more information on (a) Can the miniprobe heat shield be discarded following entry? (b) What consieration is being given to heated windows on the main probe? (c) Can the bus be put into a flyby trajectory after probe release? (Colin)

12. German ground radio station. (Bauer)

III. <u>FUTURE MEETINGS</u>

March 29 and 30, 1972	Ames Research Center
April 24 and 25, 1972	Ames Research Center
June 5-9, 1972	Place to be determined

Robert F Fellows

Robert F. Fellows, Chairman

PIONEER-VENUS
1ST SSG Mtg
MAR 7, 8 1972

MANAGEMENT APPROACH

- EXTENSION OF PIONEER
- USE PRIME CONTRACTOR
- SEPARATE VENUS PROJECT OFFICE
- TOP MANAGEMENT INVOLVEMENT
- CONDUCT SYSTEMS – TECHNOLOGY DEVELOPMENT
- PROJECT PERSONNEL INTERCHANGE

NASA–Ames

PIONEER VENUS
AMES PROJECT TEAM

PROJECT MANAGER – B. PADRICK

PROJECT SCIENTIST – L. COLIN

EXPERIMENTS – J. SPERANS

MISSION ANALYSES – R. JACKSON

TRACKING & DATA – T. GRANT

SPACECRAFT SYSTEMS – R. CHRISTIANSEN

PROBE SYSTEMS – T. CANNING

KEY ISSUES

- FY '74 START
- EARLY EXPERIMENT SELECTION
- COST CONTROL
- COST CREDIBILITY
- LIMITED EXECUTION PHASE COMPETITION
- EXPERIMENT MANAGEMENT

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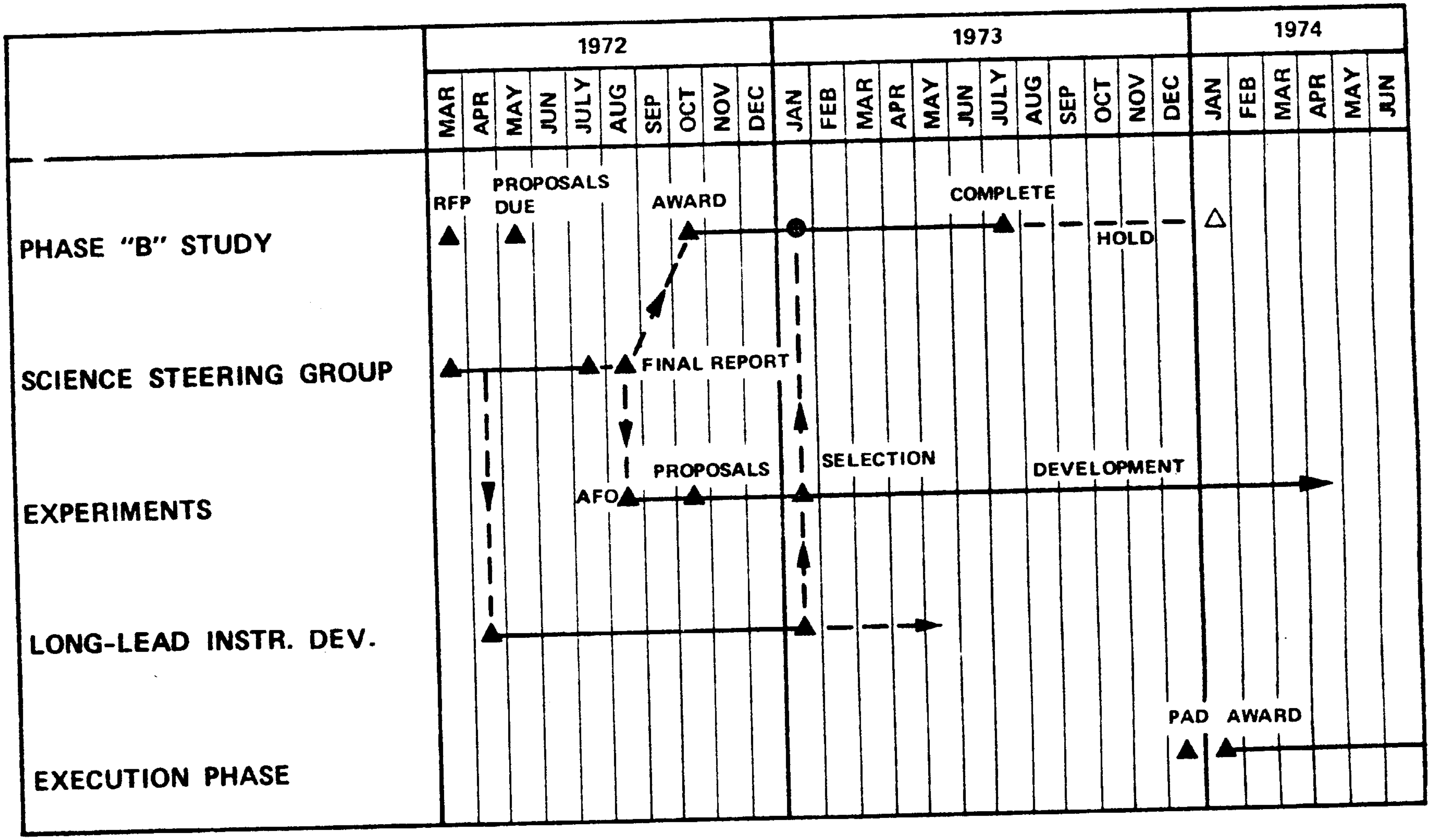
MISSION SERIES

- 1976/77 DUAL LAUNCH MULTIPLE PROBE ATMOSPHERIC-ENTRY
- 1978 SINGLE LAUNCH AERONOMY, FIELDS AND PARTICLES, AND/OR MAPPING ORBITER
- 1980 SINGLE FOLLOW-ON MULTIPLE PROBE ATMOSPHERIC-ENTRY

PHASE A SCIENCE CONSTRAINTS

	BUS	LARGE PROBE	3 SMALL PROBES	ORBITER
SCIENCE WT., #	25	64	4 ea	≥ 50
SCIENCE POWER, w	18	92	4 ea	25
DATA RATE, bps	300	80/40	1 ea	400
DATA STORAGE, bits	–	8×10^3	–	5×10^5

PIONEER VENUS MILESTONES

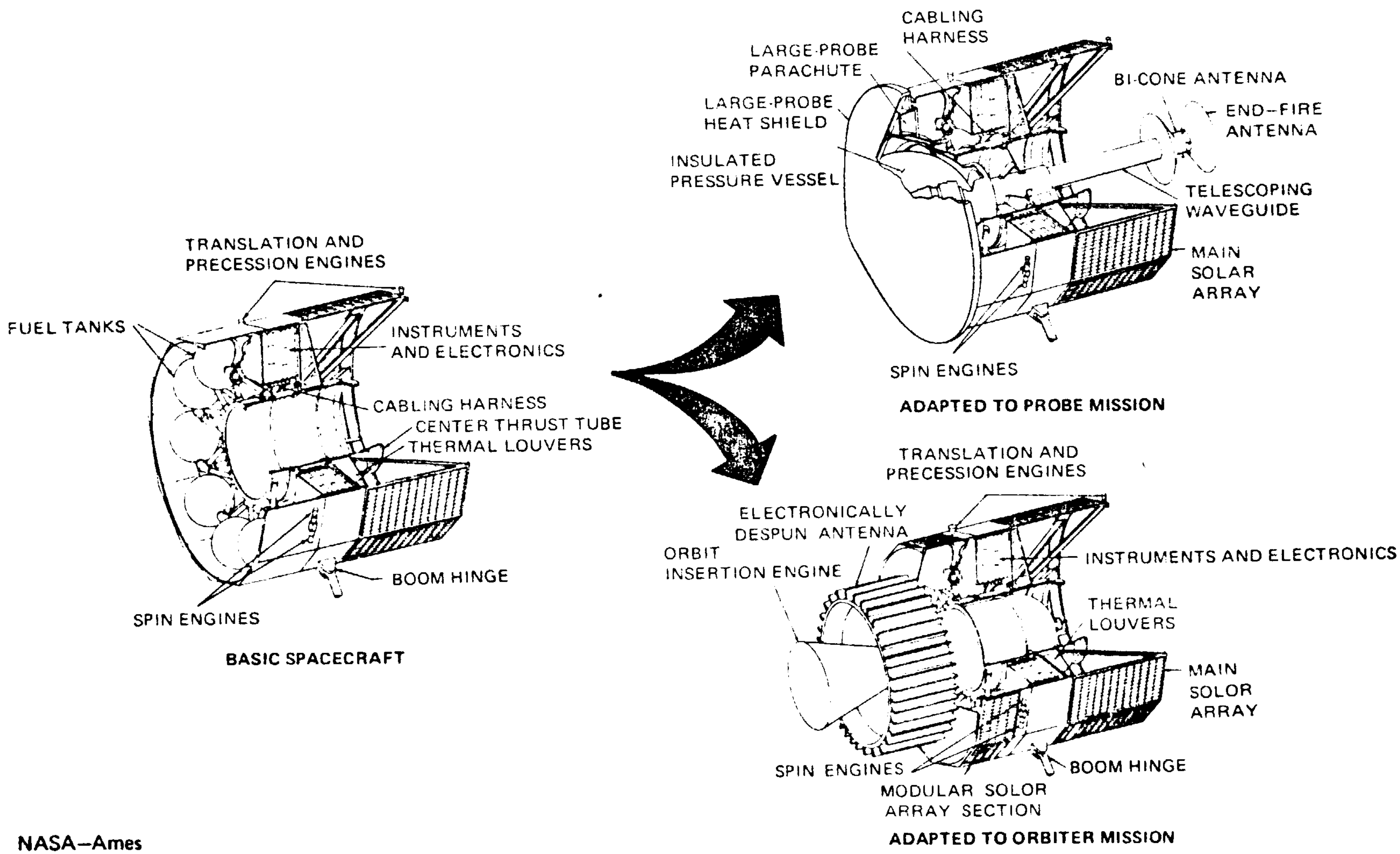


DESIGN CONSIDERATIONS

- USE OF EXISTING AND PROVEN HARDWARE AND TECHNOLOGY
- LOW COST
- SPIN STABILIZED
- DELTA LAUNCHED
- BASIC SPACECRAFT — BUS OR ORBITER

NASA—Ames

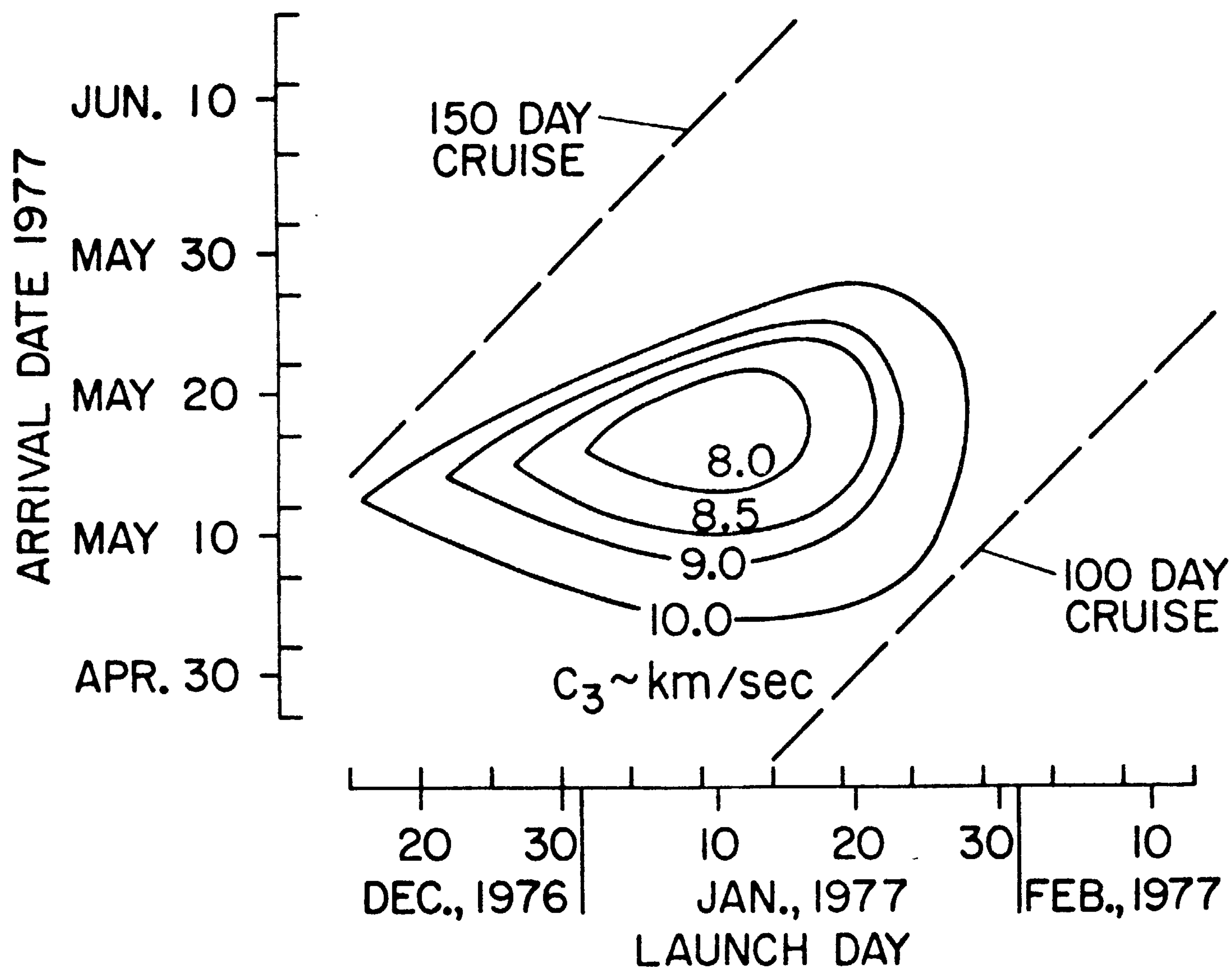
COMMONALITY CONCEPT
(POSSIBLE CONFIGURATIONS)



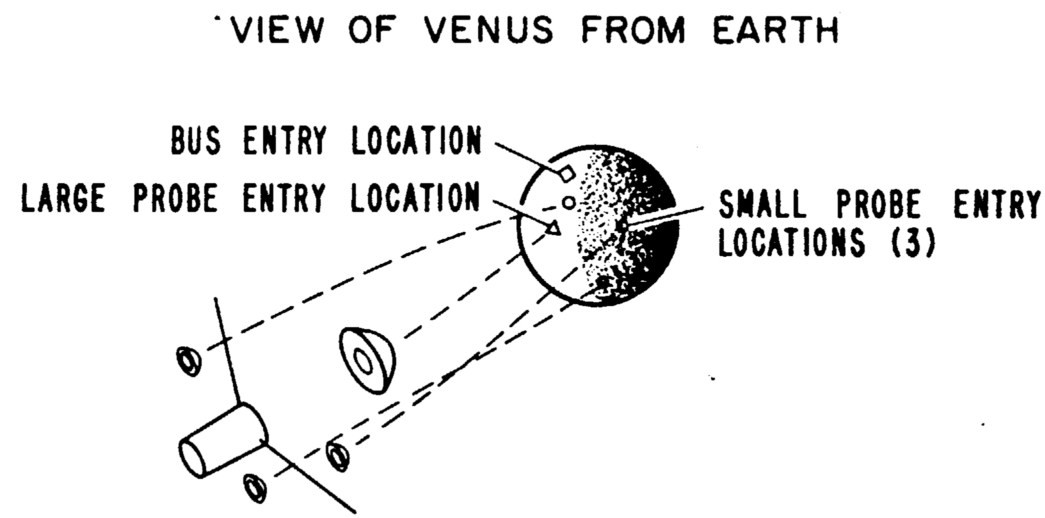
NASA–Ames

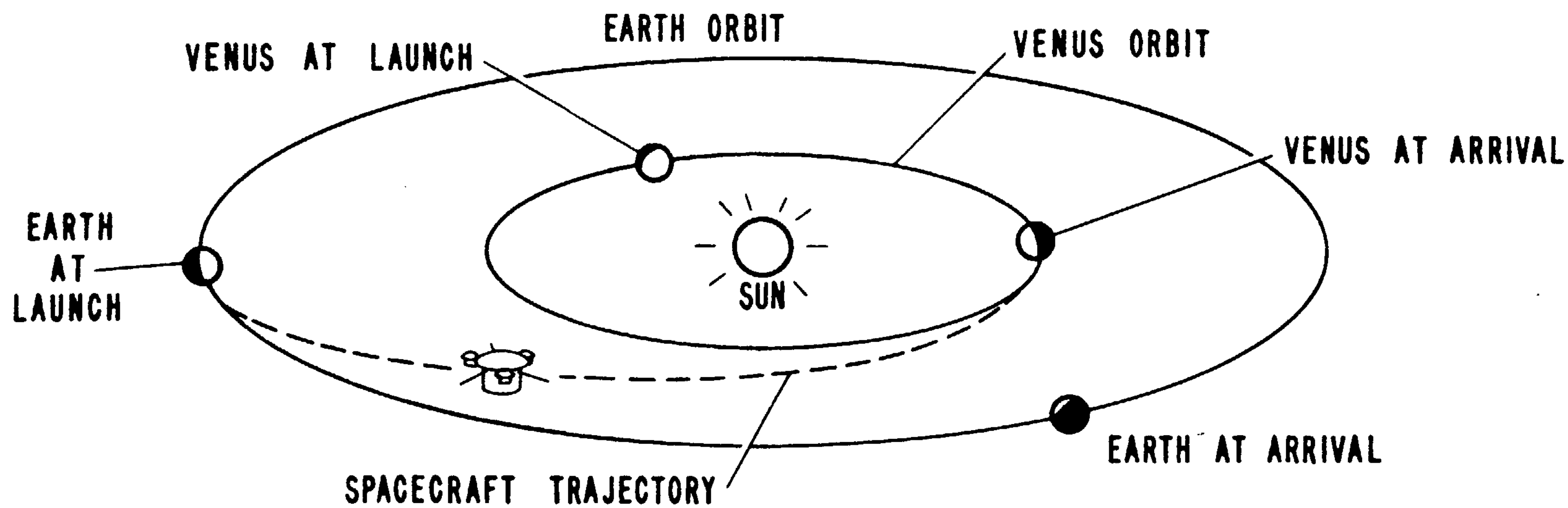
EARTH TO VENUS TRAJECTORIES

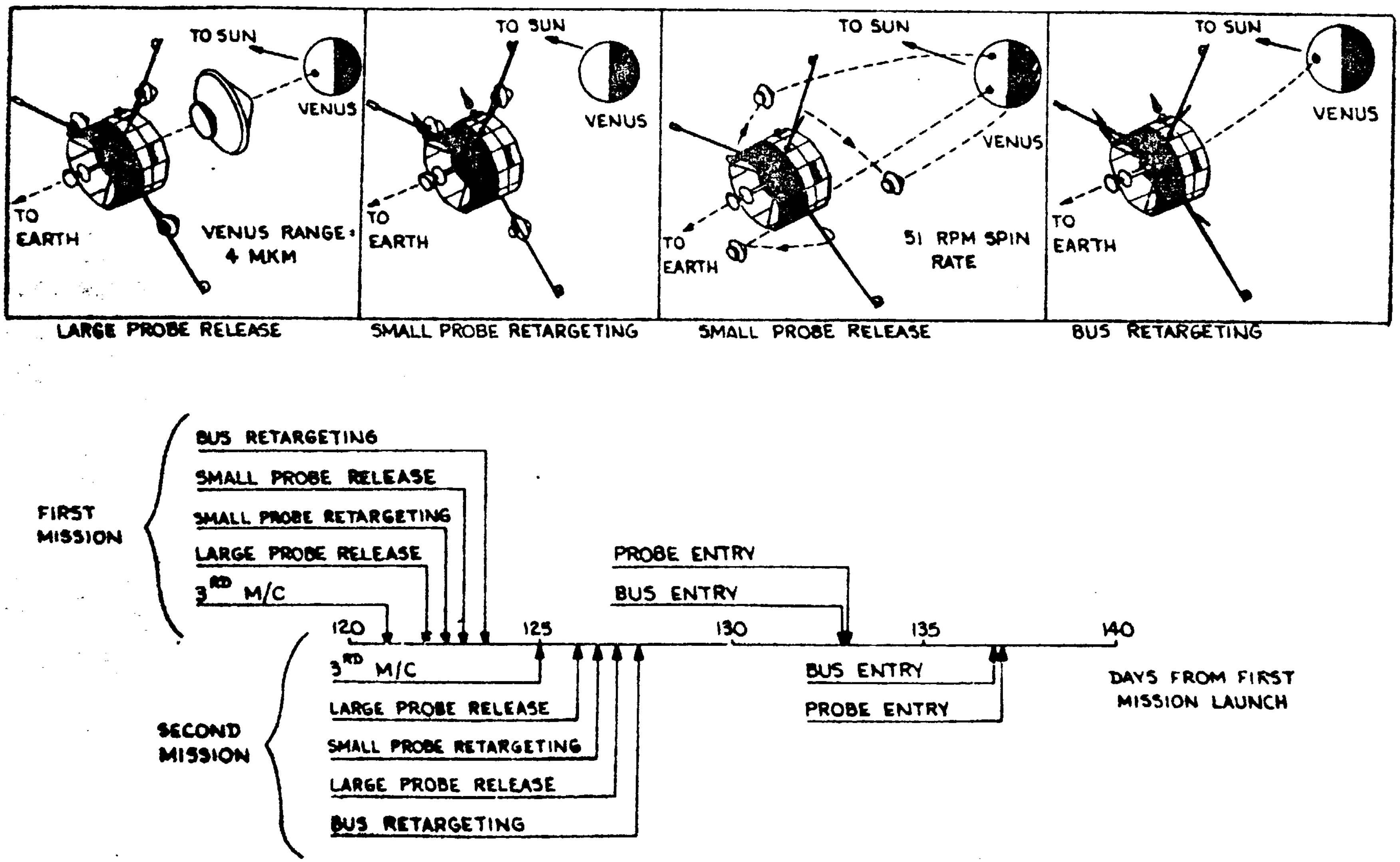
1976/1977 PROBE MISSIONS — TYPE I TRAJECTORIES



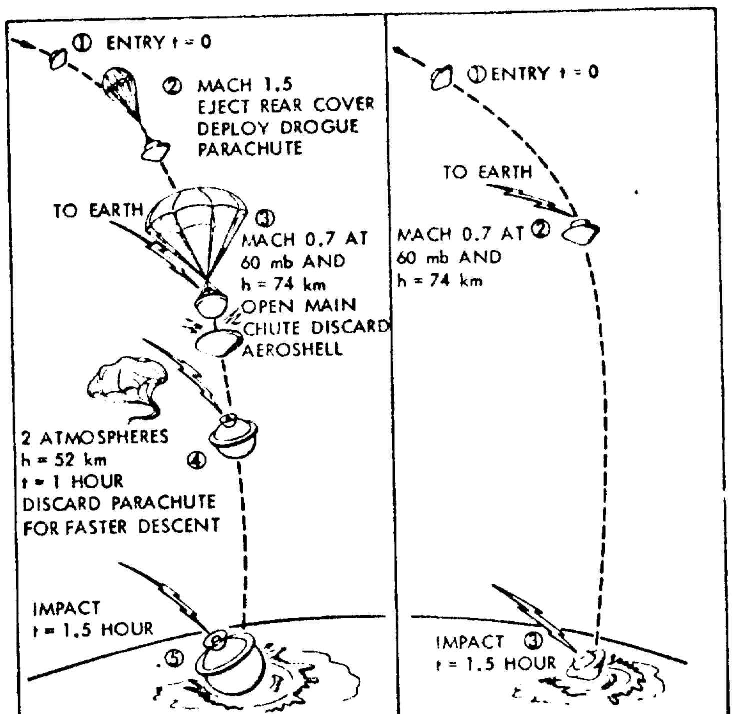
VENUS PIONEER - ENTRY PROBE MISSION SCHEMATIC DIAGRAM







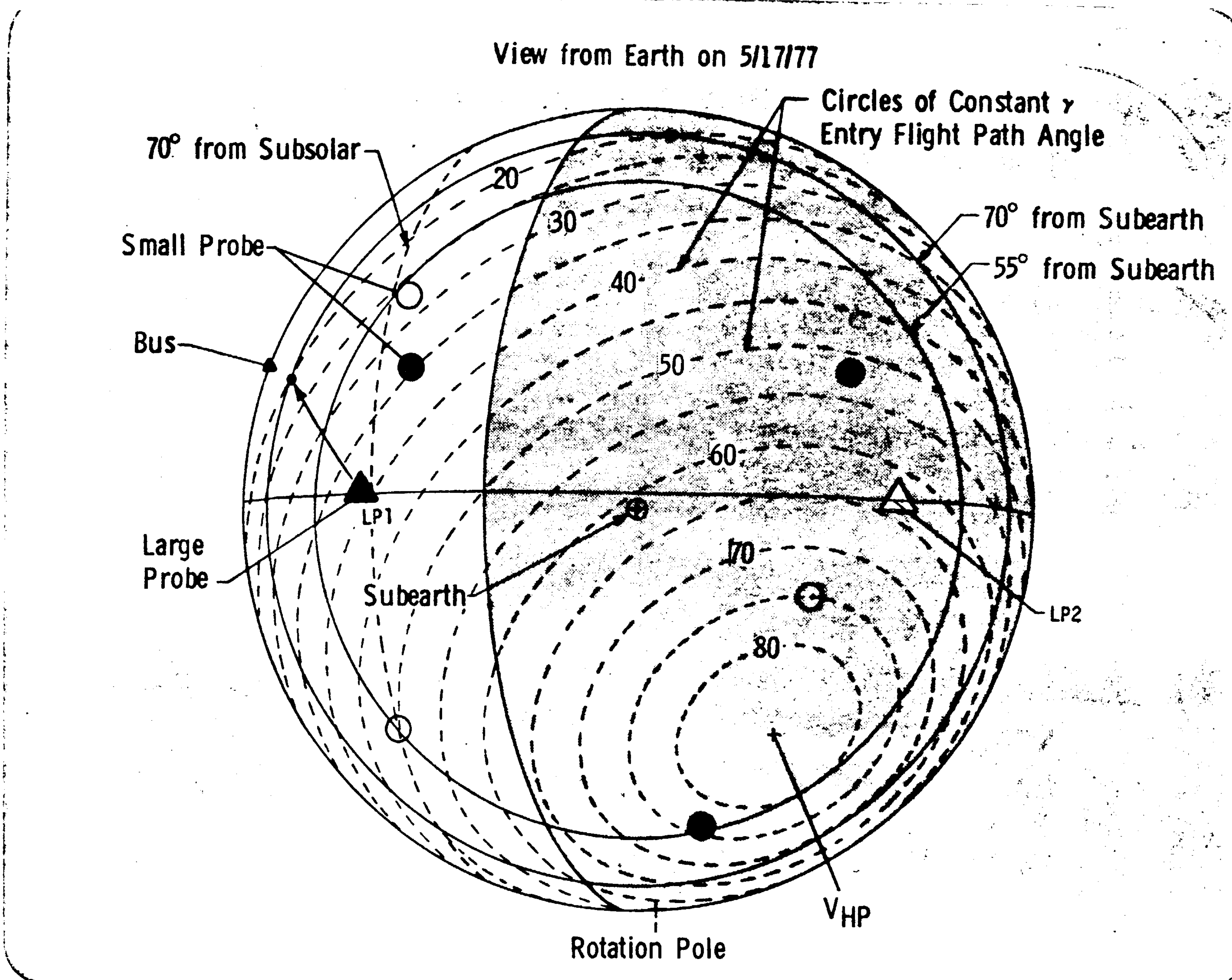
PROBE MISSION SEQUENCE



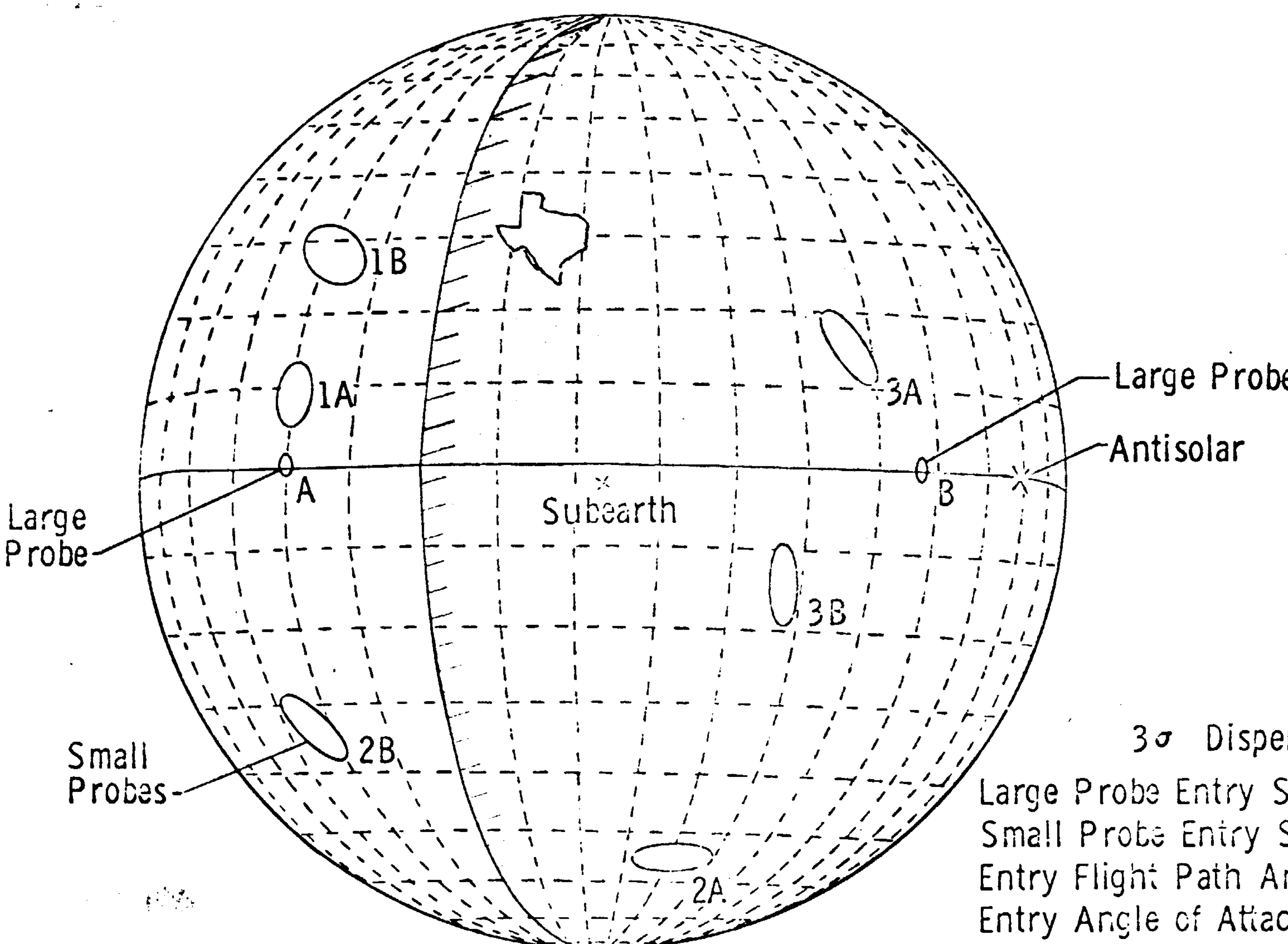
5. LARGE PROBE MAKES MEASUREMENTS

6. SMALL PROBE MAKES MEASUREMENTS

Multiple-Probe Mission Targeting Sequence


View from Earth on 5/17/77
Circles of Constant γ
Entry Flight Path Angle
70° from Subsolar
Small Probe
Bus
Large
Probe
Subearth
LP1
LP2
70° from Subearth
55° from Subearth
20
30
40
50
60
70
80
V_{HP}
Rotation Pole

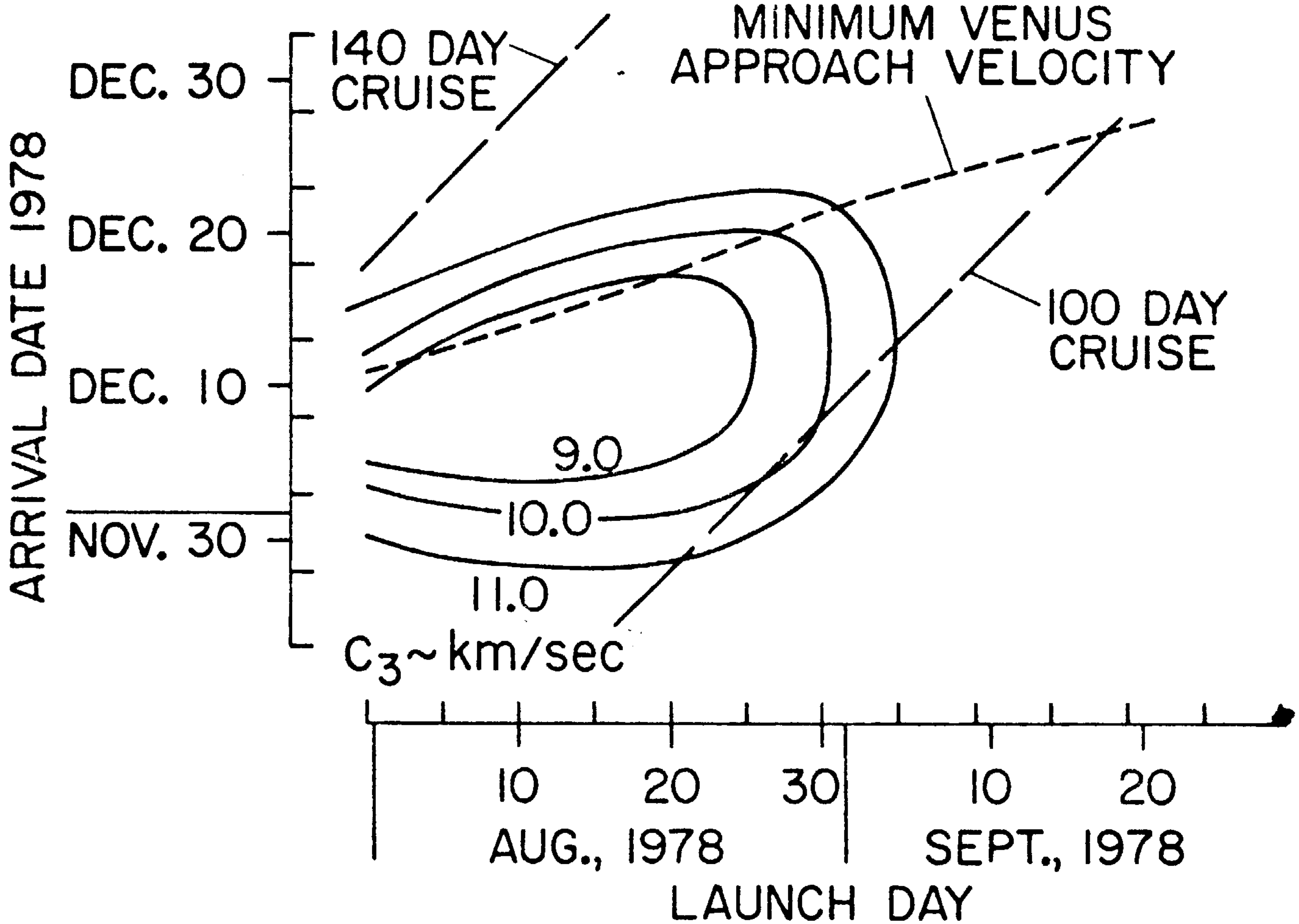
ENTRY DISPERSIONS



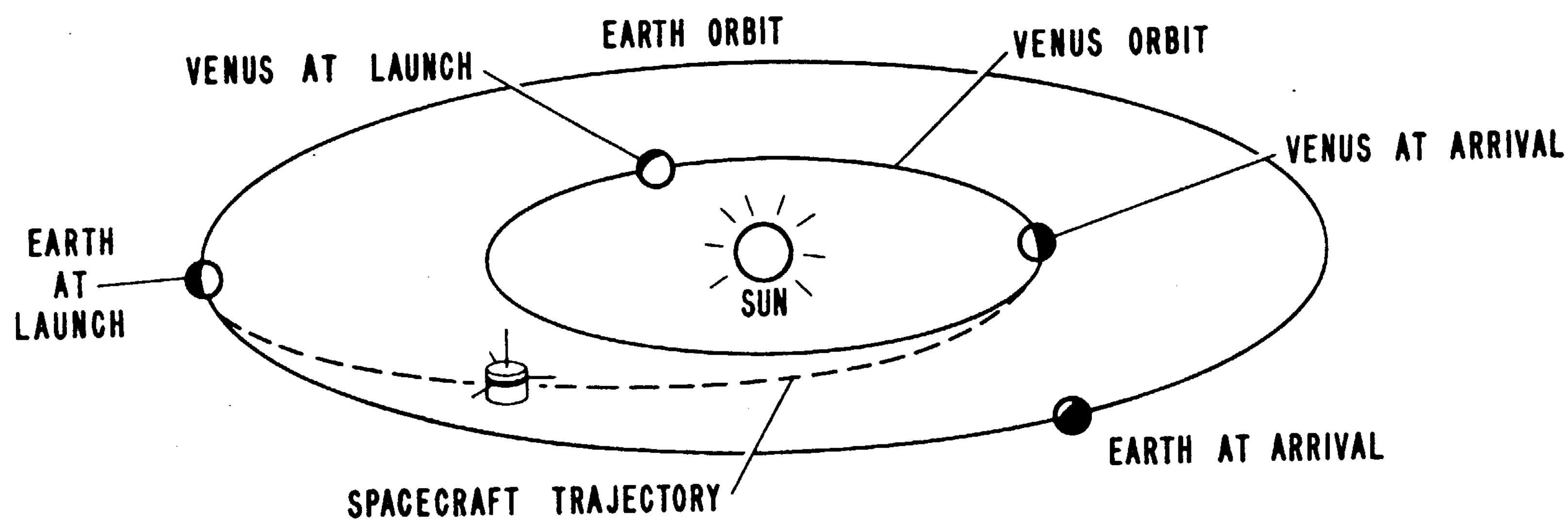
3σ Dispersions	
Large Probe Entry Site	<160 km
Small Probe Entry Site	<1000 km
Entry Flight Path Angle	$< 4^{\circ}$
Entry Angle of Attack	$< 4.2^{\circ}$
Communications Angle	$< 6.2^{\circ}$

EARTH TO VENUS TRAJECTORIES

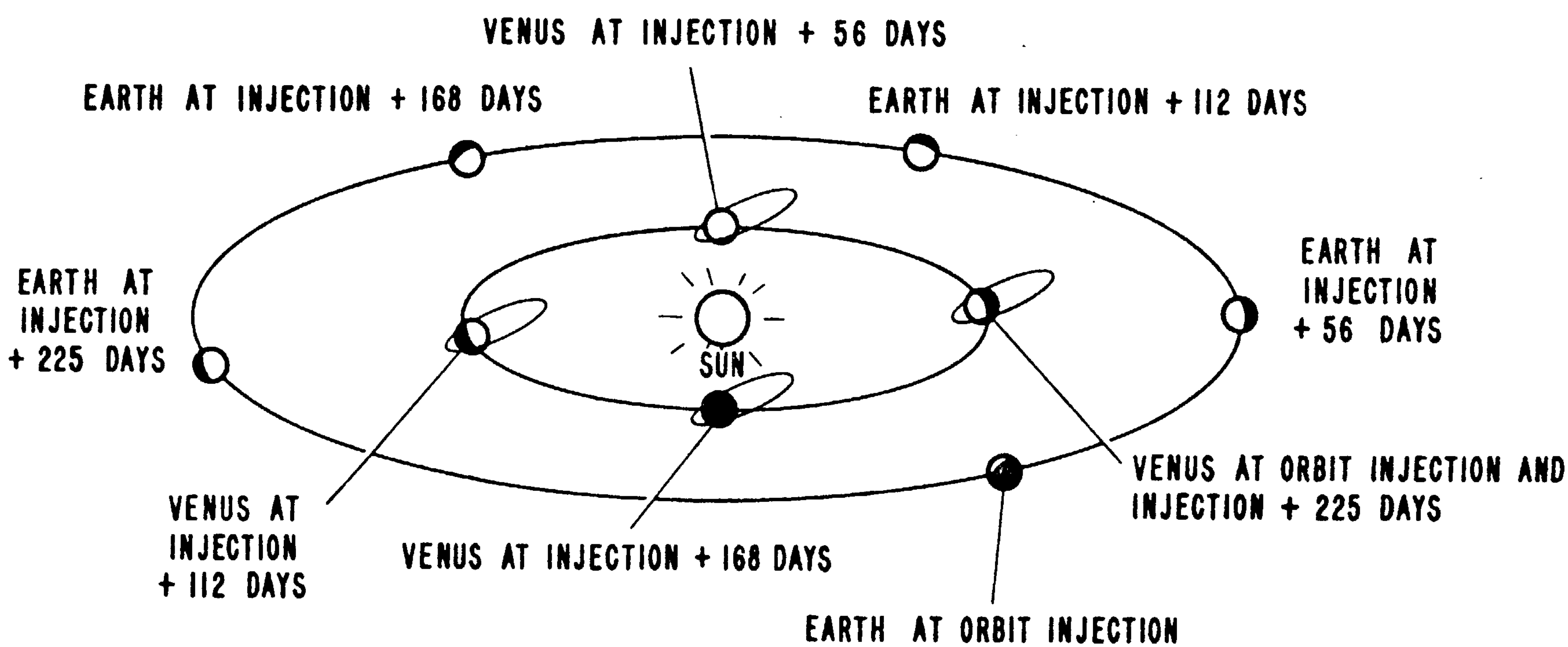
1978 ORBITER MISSION — TYPE I TRAJECTORIES

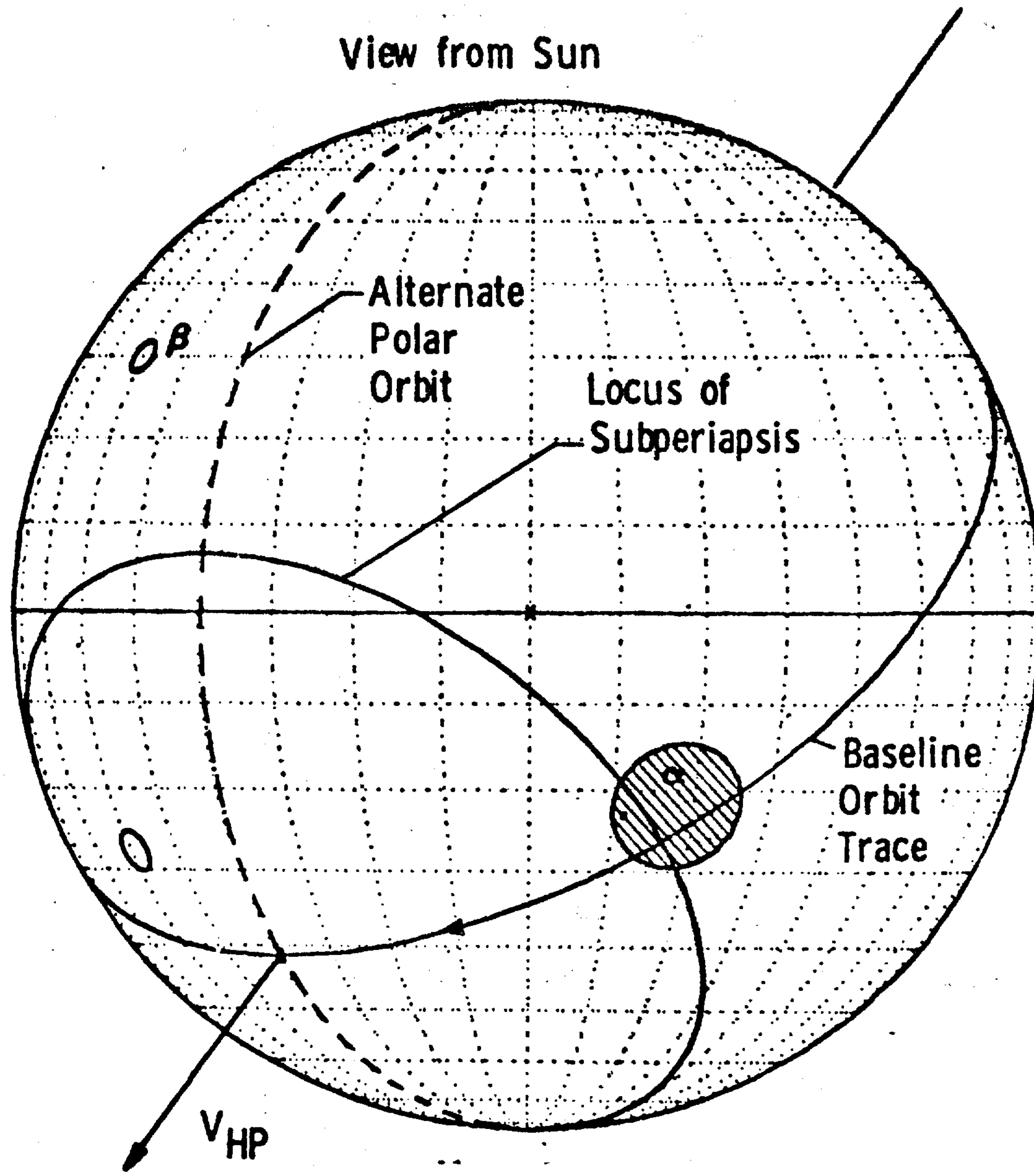


VENUS PIONEER - ORBITER MISSION SCHEMATIC



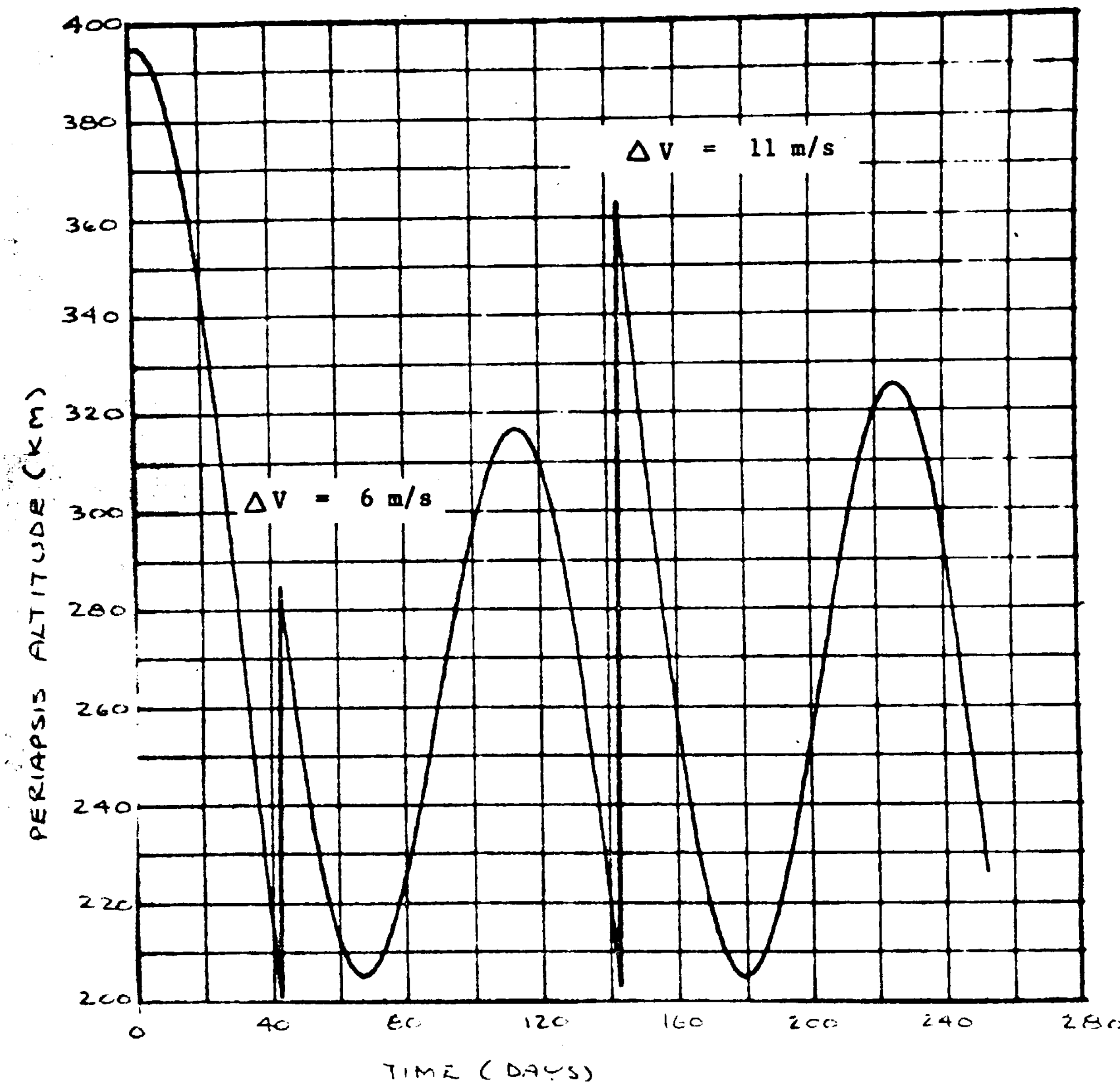
VENUS PIONEER ORBIT GEOMETRY SCHEMATIC



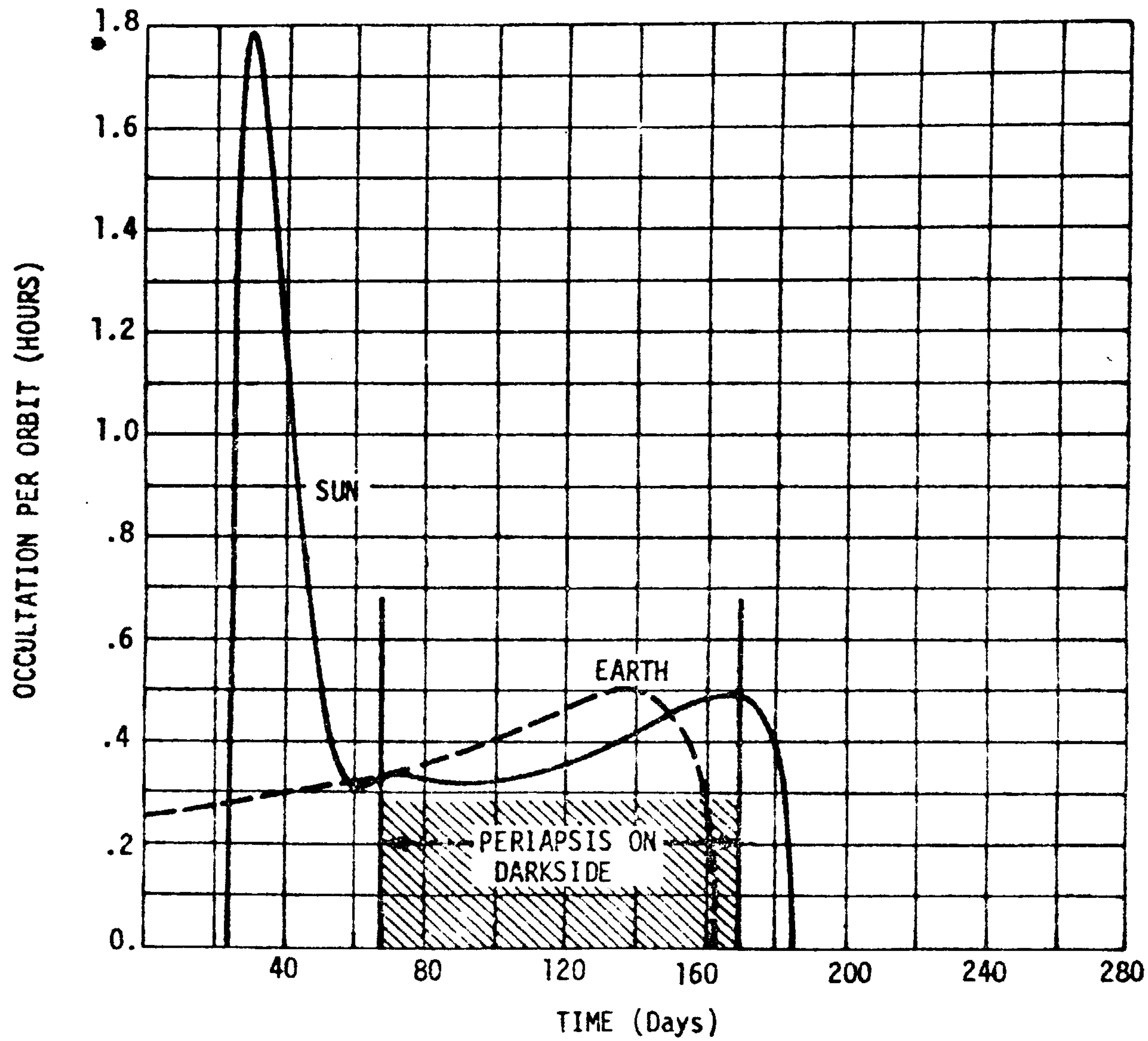


1978 ORBITER MISSION ENCOUNTER GEOMETRY

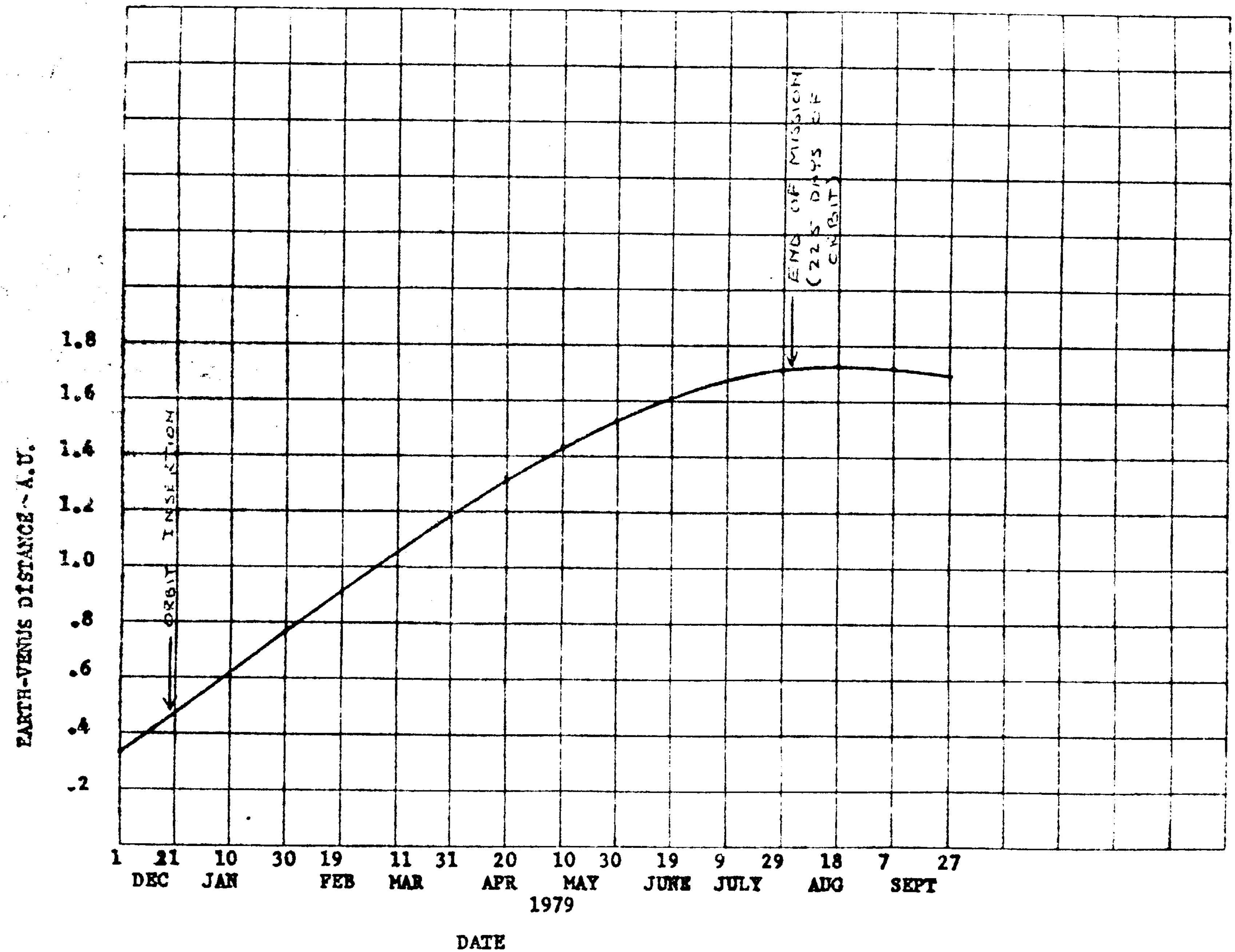
PERIAPSIS (,TORY
MINIMUM INCLINATION ORBIT



SUN AND EARTH OCCULTATION TIMES



IN ORBIT COMMUNICATIONS RANGE



INSTRUMENT CHARTS

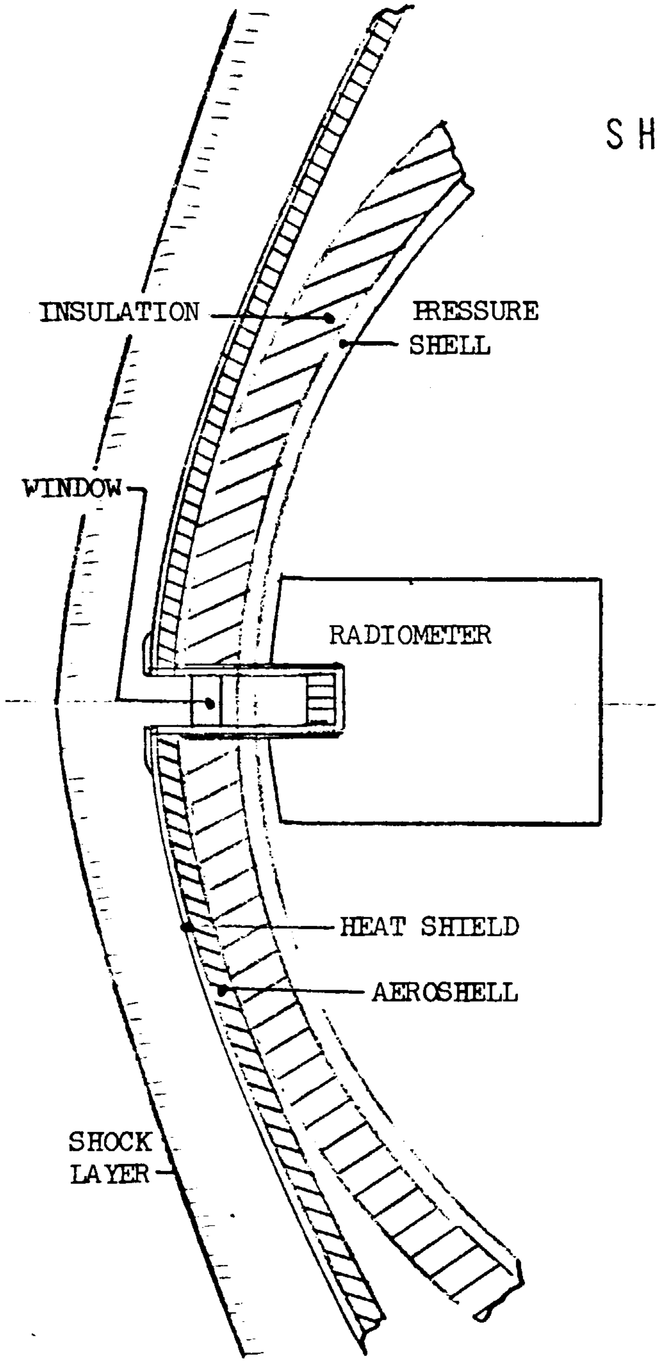
(New Instruments)

Venus Pioneer Project Office

Ames Research Center
Moffett Field, Calif.

Feb. 14, 1972

SHOCK LAYER RADIOMETER



BACKUP ATMOSPHERE COMPOSITION MEASUREMENT

OPERATED SUCCESSFULLY ON P A E T

MEASURES CO_2 N_2 AR H_2O

8 CHANNEL RADIOMETER

- 1 - OH 3060 A
- 2 - CN 3883 A , 4216 A
- 1 - C_2 SWAN 5165 A
- 4 - BACKGROUND CHANNELS

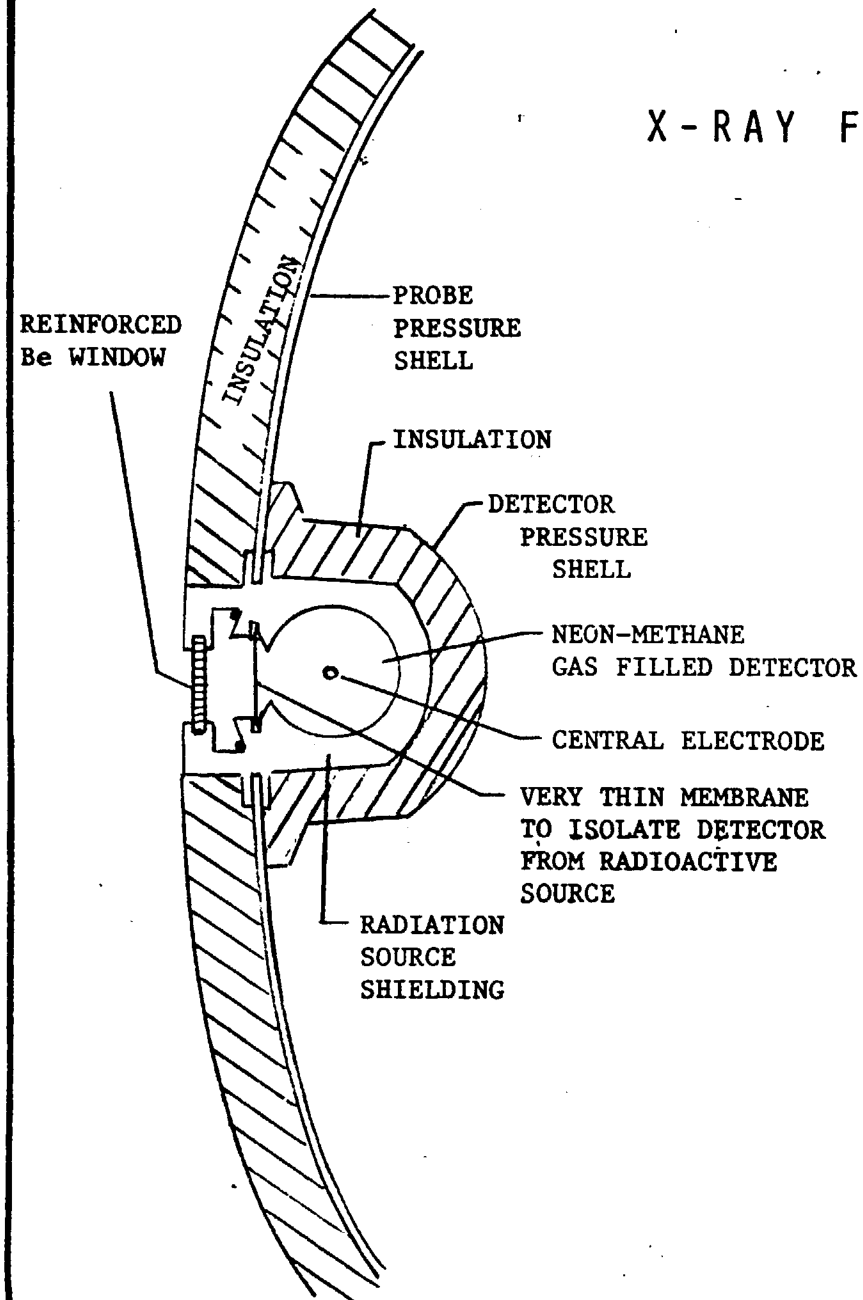
2 LBS (0.9 KG)

40 IN^3

3 WATTS

2400 BITS STORED DURING ENTRY, TRANSMITTED AT 2 BITS/FRAME DURING DESCENT ON CHUTE

X-RAY FLUOROSCOPE



RADIOACTIVE SOURCE EXCITATION

THIN WINDOW, PRESSURE SHELL AROUND INSTRUMENT

GAS FILLED PROPORTIONAL COUNTER

X - RAY PULSE HEIGHT ANALYSIS

IDENTIFIES ELEMENTS, NA - U

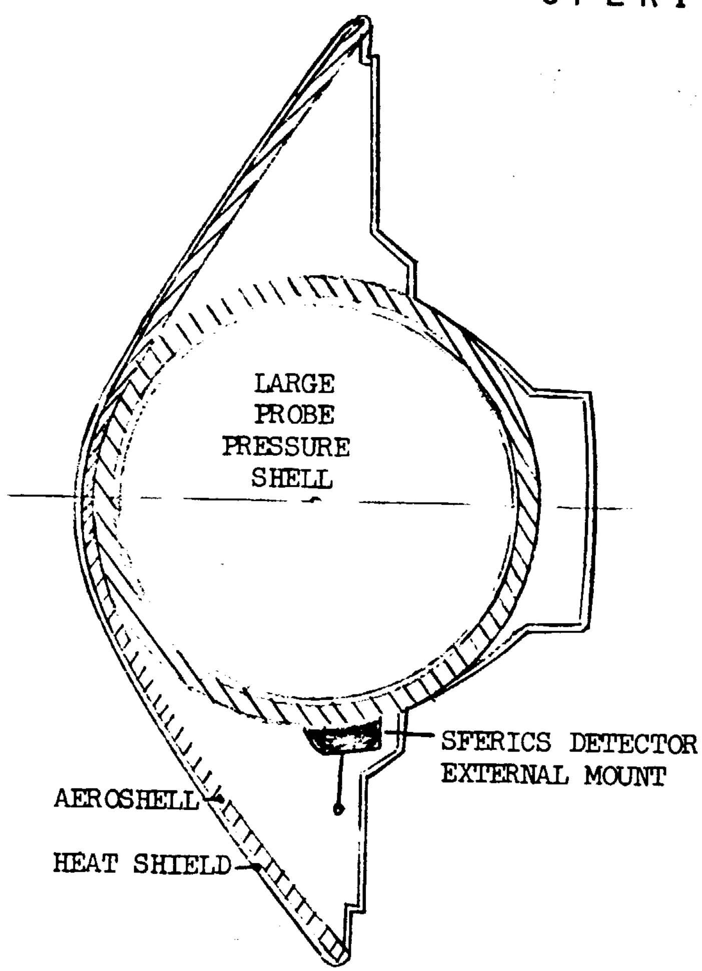
3.5 LBS (1.6 KGS)

180 IN^3

2.5 WATTS

24 BITS/KM THROUGHOUT DESCENT (1 BPS)

SFERICS DETECTOR



DETECTS NON-THERMALLY GENERATED ELECTROMAGNETIC NOISE FROM CLOUDS

BROADBAND RECEIVER AND ANTENNA

DETERMINES BACKGROUND NOISE FOR DESIGN OF FUTURE SEISMIC AND DYNAMICS EXPERIMENTS

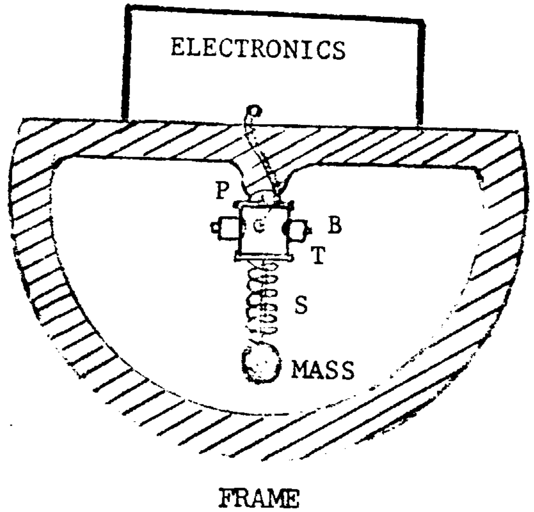
1 LB ( ).45 KG)

24 IN^3

0.6 WATTS

DATA RATE: 0.25 BPS

EXTERNAL MOUNTING FOR OPERATION 70 - 40 KM ALT.



S= SPRING
T= TRANSDUCER
B= BOLT CUTTER
P= PIVOT(BALL JOINT)

GRAVIMETER

DETERMINES SURFACE GRAVITY

DETECTS GRAVITATIONAL ANOMALIES BY CORRELATION WITH PRESSURE MEASUREMENTS

GRAVITY TO 1 PART IN 10^5

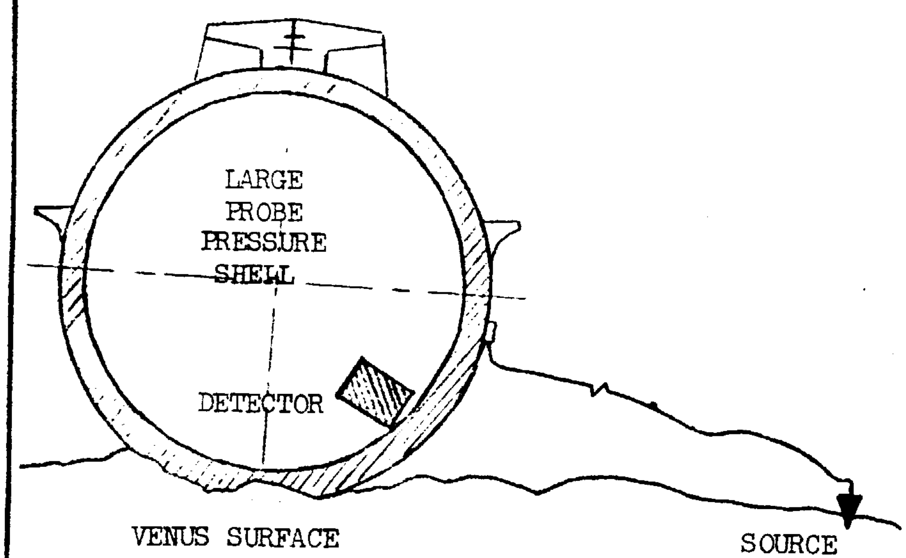
1 LB (0.45KG)

10 IN^3

1 WATT

1 SAMPLE 50 BITS, ON THE SURFACE

SURFACE COMPOSITION ANALYZER



NEUTRON CAPTURE GAMMA RADIATION

ELEMENT IDENTIFICATION BY RADIATION SIGNATURE

ATMOSPHEREIC COMPOSITION - 3 SAMPLES

SURFACE COMPOSITION - 2-3 SAMPLES

SURFACE/SUB-SURFACE TEMPERATURE

7.5 LB (3.4KG)

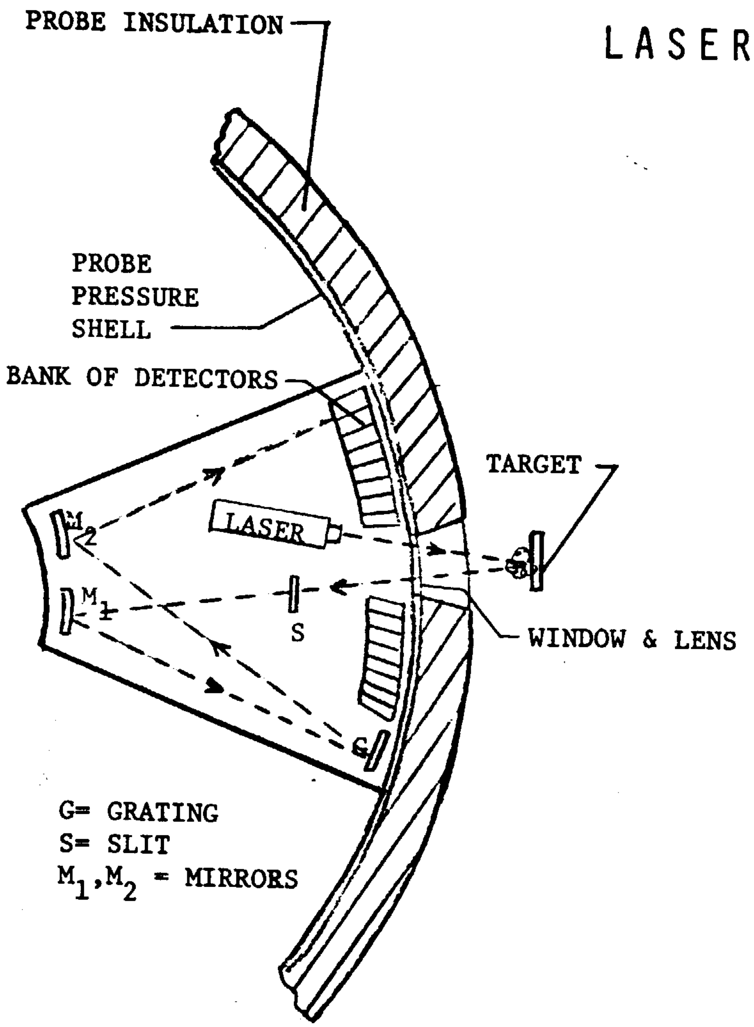
100 IN^3

3 WATTS

ATMOSPHERE SAMPLE: 4000 BITS IN 900 SECONDS (4.5BPS)

SURFACE SAMPLE: 8000 BITS IN 300 SECONDS (27BPS)

LASER MICROPROBE



EMISSION SPECTROGRAPH

DETERMINES COMPOSITION OF: AEROSOLS
ATMOSPHERIC GASES
DUST PARTICLES

DEDICATED ANALYSIS, UP TO 20 CHANNELS

QUANTITATIVE MEASUREMENT

10 LBS (4.5KGS)

400 IN^3

6 WATTS

20 CHANNELS @ 1 SAMPLE/300 SECONDS (1 BPS)

PAYLOAD CHARTS

Venus Pioneer Project Office

Ames Research Center
Moffett Field, Calif.

Feb. 14, 1972

NOTES ... PAYLOAD TABLES

WEIGHT: Weight shown is for entire instrument, including sensors, inlets, etc. Does not include booms or probe windows.

POWER: Power shown is nominal average power required by the instrument, measured at the instrument. It does not indicate peak power demands

DATA REQUIREMENTS: Samples per kilometer is the nominal rate at the time of maximum descent velocity, just after blackout period. (about 70 Km.) The number of samples per Km will increase as the probe descends into denser atmosphere.

DEVELOPMENT STATUS, REQUIREMENT:

<u>Flown (S/C)</u>: instrument is developed; has flown on a spacecraft
<u>Flown (A/C)</u>: instrument is developed; has flown on an aircraft
<u>Under Development</u>: Development is presently in progress
<u>Conceptual</u>: No development has been started; instrument is merely a concept at this time.

<u>Minor Modification</u>: Instrument is operationally ready for a Venus mission. Interface and packaging changes are required.
<u>Major Modification</u>: Instrument is operational in a form which is not suitable for the Venus missions. Must be miniaturized, space qualified, etc.

DEVELOPMENT COMPLEXITY:

<u>Low</u>: Development effort required to produce the instrument for the Venus mission is routine engineering task; technical risk is low.

<u>Moderate</u>: Development effort is difficult but feasible; technical risk is about average for space science instruments

<u>High</u>: Instrument is extremely complex, has inherent problems which appear to be pushing the current "state of the art"; technical risk is relatively high. NOTE: In many such cases simpler approaches to accomplish the same functions may be feasible.

TOP VERTICAL

TABLE A

NOMINAL PAYLOAD – LARGE PROBE

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS BITS/SAMPLE	DATA REQUIREMENTS SAMPLES/KM	BITS/sec	DEVELOPMENT TASK STATUS; REQUIREMENT	DEVELOPMENT TASK COMPLEXITY	SYSTEM IMPACT	REMARKS
TEMPERATURE GAUGES	1.5/0.68	0.2	12	8	4	0.5	FLOW (S/C); MINOR MODIFICATION	LOW	PRESSURE SHELL PENETRATION	
PRESSURE GAUGES	2.0/0.90	0.75	16	8	4	0.5	FLOW (S/C); MINOR MODIFICATION	LOW	PRESSURE SHELL PENETRATION	
ACCELEROMETERS	2.8/1.27	3.0	40	40	(a)	~3	FLOWN (S/C); MINOR MODIFICATION	LOW	LOCATE AT C/MASS	(a) DURING HIGH G DECELERATION PEAK-DATA STORAGE REQUIRED FOR PLAY-BACK AFTER BLACKOUT (b) PLAYBACK & R/T TLM RATE AFTER BLACKOUT
NEUTRAL PARTICLE MASS SPECTROMETER	10.0/4.5	12.0	600	720	0.5	12	UNDER DEVELOPMENT	HIGH	SAMPLE INLET	0-140 AMU
SOLAR RADIOMETER	4.0/1.8	4.0	120	16	4	2	UNDER DEVELOPMENT*	HIGH	SOLAR VIEWING PRESSURE SHELL PENETRATION	REQUIRES SIMULTANEOUS MEASUREMENTS IN SOLAR & ANTISOLAR DIRECTIONS
CLOUD PARTICLE SIZE ANALYZER	8.0/3.65	8.0	200	256	8	32	FLOWN (A/C); MAJOR MODIFICATION	HIGH	PRESSURE SHELL PENETRATION	
NEPHELOMETER	1.6/0.73	2.5	72	8	10	3	FLOWN (A/C); MAJOR MODIFICATION	MODERATE	PRESSURE SHELL WINDOW(S)	MOUNT TO VIEW AT 90 DEGREES TO THE DESCENT AXIS
HYGROMETER	1.0/0.45	0.3	18	4	6	0.8	FLOWN (A/C); MAJOR MODIFICATION	LOW	PRESSURE SHELL PENETRATION	
WIND/CLOUD/ALTIMETER RADAR	11.0/5.0	15.0	500	32	6	8	CONCEPTUAL; LIKE APOLLO, VIKING	HIGH	ANTENNA, WOBBLE LIMIT	
AUREOLE DETECTOR	2.5/1.14	3.0	80	8	4	1	UNDER DEVELOPMENT	MODERATE	SOLAR VIEWING, SPIN	MAY BE EXTERNALLY MOUNTED
THERMAL FLUX DET.	2.6/1.2	2.0	100	8	4	1	UNDER DEVELOPMENT*	HIGH	PRESSURE SHELL PENETRATION OR WINDOW	SENSOR MOUNTED TO LOOK DOWNWARD TOWARD PLANET
EVAPORIMETER-CONDENSIMETER	2.8/1.3	10.0	120	320	1	10	CONCEPTUAL	HIGH	PRESSURE SHELL WINDOWS HEATED SENSOR	REQUIRES SHORT BOOM EXTERNAL OF SPHERE
MAGNETOMETER	1.5/0.7	2.0	60	24	1	0.8	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	BOOM, MAGNETIC CLEANLINESS	

*MAY BE COMBINED

(a) HIGH SPEED ENTRY DECELERATION RECORDED AT ~200 bps, READ OUT LATER DURING SLOW SPEED DESCENT AT ~3 bps.

TOP VERTICAL

TABLE B

ADDITIONAL INSTRUMENTS – LARGE PROBE

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS BITS/SAMPLE	DATA REQUIREMENTS SAMPLES/KM	BITS/sec	DEVELOPMENT TASK STATUS; REQUIREMENT	DEVELOPMENT TASK COMPLEXITY	SYSTEM IMPACT	REMARKS
ATMOSPHERIC OPTICAL SPECTROMETER	2.0/0.9	3.0	30	100	1 (a)	(a)	FLOWN (S/C); MINOR MODIFICATION	MODERATE	PRESSURE SHELL WINDOW	
CLOUD PARTICLE MASS SPECTROMETER	8.0/3.65	8.0	200	256	2.5	21	CONCEPTUAL	HIGH	SAMPLE INLET	3-300 AMU RANGE
X-RAY SPECTROMETER	3.5/1.6	2.5	180	24	1	0.8	CONCEPTUAL	HIGH	THIN WINDOW IN SHELL	
SFERICS DETECTOR	1.0/0.45	0.6	10	4	2	0.25	CONCEPTUAL	LOW	ANTENNA	
NOISE DETECTOR	1.0/0.45	0.6	10	4	6 (b)	0.8	CONCEPTUAL	LOW	ANTENNA	
GRAVIMETER	1.0/0.45	1.0	8	8	6 (b)	1.6	CONCEPTUAL	MODERATE	UNKNOWN	SURFACE USE ONLY
SURFACE COMPOSITION ANALYZER	6.0/2.7	2.5	120	16	1 (b)	0.5	CONCEPTUAL	MODERATE	BOOM MOUNTED SURFACE	MAY MEASURE ATMOSPHERIC COMPOSITION DURING DESCENT
LASER MICROPROBE	10.0/4.5	6.0	450	180	1	6	UNDER DEVELOPMENT	HIGH	PRESSURE SHELL PROTRUSION & WINDOW	
PENETROMETER	0.5/0.23	1.0	48	8	1 (b)	0.25	CONCEPTUAL	MODERATE	PRESSURE SHELL PENETRATION	SURFACE USE ONLY
MINISEISMOMETER	1.3/0.6	1.0	80	16	6 (b)	3.2	CONCEPTUAL	MODERATE	UNKNOWN	SURFACE USE ONLY

(a) OPERATES DURING HIGH DECELERATION REENTRY PERIOD ONLY (1 MEASUREMENT CYCLE OF 100 BITS STORED AND READ OUT LATER DURING SLOW SPEED DESCENT AT ~1 BIT/DATA FRAME).
(b) OPERATES ON SURFACE AT BIT RATE INDICATED.

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TOP VERTICAL

TABLE C

NOMINAL PAYLOAD – SMALL PROBES

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (in.^{3})	DATA REQUIREMENTS		BITS/sec	DEVELOPMENT TASK		SYSTEM IMPACT	REMARKS
				BITS/SAMPLE	SAMPLES/KM		STATUS; REQUIREMENT	COMPLEXITY		
TEMPERATURE GAUGES	1.0/0.45	0.2	10	8	5	1.3	FLOWN (S/C); MINOR MODIFICATION	LOW	PRESSURE SHELL PENETRATION	
PRESSURE GAUGES	1.0/0.45	0.75	10	8	5	1.3	FLOWN (S/C); MINOR MODIFICATION	LOW	PRESSURE SHELL PENETRATION	
SOLAR RADIATION DETECTOR	0.6/0.27	0.1	4	8	2.5	0.7	CONCEPTUAL	LOW	PRESSURE SHELL WINDOW	MAY BE EXTERNALLY MOUNTED
ACCELEROMETER	0.7/0.32	0.4	2	8	2.5	0.7	FLOWN (S/C); MINOR MODIFICATION	LOW	LOCATION AT C/MASS	SINGLE AXIS; REQUIRES DATA STORAGE TO RECORD HIGH SPEED DECELERATION; PROVIDES SURFACE IMPACT INDICATION

TOP VERTICAL

TABLE D

ADDITIONAL INSTRUMENTS – SMALL PROBES

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (in.^{3})	DATA REQUIREMENTS		BITS/sec	DEVELOPMENT TASK		SYSTEM IMPACT	REMARKS
				BITS/SAMPLE	SAMPLES/KM		STATUS; REQUIREMENT	COMPLEXITY		
NEPHELOMETER	0.9/0.40	1.5	7	8	5	1.3	FLOWN (A/C); EXTENSIVE MODIFICATION, MINIATURIZATION	LOW-MODERATE	WINDOW(S) IN PRESSURE SHELL	THIS FUNCTION MAY BE ACCOMPLISHED BY ADDING LIGHT SOURCE TO SOLAR RADIOMETER
SFERICS DETECTOR	0.9/0.40	0.5	8	4	1.3	0.2	CONCEPTUAL	LOW	ANTENNA	MAY BE EXTERNALLY MOUNTED
MAGNETOMETER	1.2/0.54	1.0	18	12	1.3	0.5	CONCEPTUAL	LOW	BOOM, MAGNETIC CLEANLINESS	SENSOR LOCATED OUTSIDE OF PRESSURE VESSEL
GRAVIMETER	1.0/0.45	0.8	6	8	6 (b)	1.6	CONCEPTUAL	MODERATE	UNKNOWN	SURFACE USE ONLY
SURFACE APPROACH INDICATOR	2.0/0.9	3.0	27	4	5	0.7	CONCEPTUAL	MODERATE	ANTENNA, PROBE STABILITY	
TRANSPONDER	1.5/0.7	6.0	40	–	–	–	FLOWN (S/C); MINIATURIZATION	MODERATE	ANTENNAS	

(b) OPERATES ON SURFACE AT BIT RATE INDICATED.

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TOP VERTICAL

TABLE E

NOMINAL PAYLOAD – PROBE BUS

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS		BITS/sec	DEVELOPMENT TASK		SYSTEM IMPACT	REMARKS
				BITS/SAMPLE	SAMPLES/KM		STATUS; REQUIREMENT	COMPLEXITY		
NEUTRAL PARTICLE MASS SPECTROMETER	10.0/4.5	12.0	500	400	10	67	UNDER DEVELOPMENT	HIGH	SAMPLE INLET	0-140 AMU
ELECTRON TEMPERATURE PROBE	2.0/0.9	2.0	80	40	20	13.3	FLOWN (S/C); MINOR MODIFICATION	MODERATE	ANTENNA	
ION RETARDING POTENTIAL ANALYZER	2.4/1.1	2.5	100	400	6	40	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	ORIENTATION SAMPLE INLET	
UV PHOTOMETERS	1.6/0.7	1.5	80	32	60	32	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	VIEWING	
SOLAR WIND PROBE	7.0/3.2	4.0	300	32	20	10.7	FLOWN (S/C); MINOR MODIFICATION	MODERATE	INLET	ALSO CRUISE-MODE MEASUREMENT
ION MASS SPECTROMETER	3.0/1.4	1.0	330	280	16	74	FLOWN (S/C); MAJOR MODIFICATION	HIGH	SAMPLE INLET	

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TOP VERTICAL

TABLE F

ADDITIONAL INSTRUMENTS – PROBE BUS

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS		BITS/sec	DEVELOPMENT TASK		SYSTEM IMPACT	REMARKS
				BITS/SAMPLE	SAMPLES/KM		STATUS; REQUIREMENT	COMPLEXITY		
ELECTRIC FIELD DETECTOR	5.0/2.3	3.5	140	20	20	6.7	FLOWN (S/C); MINOR MODIFICATION	MODERATE	ANTENNAS	ALSO CRUISE MODE MEASUREMENT
NEUTRAL PRESSURE GUAGE	4.0/1.8	2.5	120	16	20	5.3	FLOWN (S/C); MINOR MODIFICATION	MODERATE	INLET	
UV SPECTROMETER	4.4/2.0	2.0	120	72	20	24	FLOWN (S/C); MINOR MODIFICATION	MODERATE	VIEWING	
MAGNETOMETER	5.0/2.3	3.0	240	24	20	8	FLOWN (S/C); MINOR MODIFICATION	MODERATE	BOOM	ALSO CRUISE MODE MEASUREMENT
PHOTOELECTRON SPECTROMETER	4.0/1.8	2.5	120	80	20	27	FLOWN (S/C); MINOR MODIFICATION	MODERATE	INLET	

TOP VERTICAL

TABLE G

NOMINAL PAYLOAD – ORBITER

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS BITS/SAMPLE	DATA REQUIREMENTS SAMPLES/KM	BITS/sec	DEVELOPMENT TASK STATUS; REQUIREMENT	DEVELOPMENT TASK COMPLEXITY	SYSTEM IMPACT	REMARKS
MAGNETOMETER	5.0/2.3	3.0	240	24	5	2	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	BOOM, MAG CLEANLINESS	ALSO CRUISE-MODE MEASUREMENT
SOLAR WIND PROBE	7.0/3.2	4.0	300	32	5	2.7	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	INLET	ALSO CRUISE-MODE MEASUREMENT
NEUTRAL PARTICLE MASS SPECTROMETER	10.0/4.5	12.0	500	280	3	14	UNDER DEVELOPMENT	HIGH	INLET	
UV SPECTROMETER	4.4/2.0	2.0	120	72	10	12	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	VIEWING	
ELECTRON TEMPERATURE PROBE	2.0/0.9	1.5	90	40	10	7	FLOWN (S/C); MINOR MODIFICATION	MODERATE	ANTENNA	
ION RPA	3.0/1.4	2.5	100	32	5	2.7	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	INLET	
IR RADIOMETER	8.8/4.0	6.0	400	40	10	7	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	ANTENNA	
MICROWAVE	15.0/6.8	9.0	500	600	2	20	CONCEPTUAL	HIGH	ANTENNA	
ION MASS SPECTROMETER	3.0/1.4	1.0	330	280	3	14	FLOWN (S/C); MAJOR MODIFICATION	HIGH	INLET	

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TOP VERTICAL

TABLE H

ADDITIONAL INSTRUMENTS – ORBITER

INSTRUMENT TYPE	WEIGHT (Lb)/(Kg)	POWER (Watts)	VOL (In.^{3})	DATA REQUIREMENTS		BITS/sec	DEVELOPMENT TASK		SYSTEM IMPACT	REMARKS
				BITS/SAMPLE	SAMPLES/MINUTE		STATUS; REQUIREMENT	COMPLEXITY		
RADAR ALTIMETER	20.0/9.0	25	700	40	10	7	FLOWN (S/C); MAJOR MODIFICATION	HIGH	ANTENNA VEHICLE STABILITY, POWER	
ELECTRIC FIELD DETECTOR	5.0/2.3	3.5	140	32	5	2.7	FLOWN (S/C); MINOR MODIFICATION	MODERATE	ANTENNAS	ALSO CRUISE-MODE MEASUREMENT
NEUTRAL PRESSURE GAUGE	4.0/1.8	2.5	120	8	12	1.6	FLOWN (S/C); MINOR MODIFICATION	MODERATE	INLET, ORIENTATION	
H.E. CHARGED PARTICLE DETECTORS	7.0/3.2	3.0	300	40	20	13.3	FLOWN (S/C); MAJOR MODIFICATION	MODERATE	THERMAL CONTROL	ALSO CRUISE-MODE MEASUREMENT
SPIN-SCAN TV	15.0/6.8	10.0	450	2×10^5	0.02	(a)	FLOWN (S/C); MAJOR MODIFICATION	HIGH	VIEWING, STABILITY, POWER DATA	REQUIRES DATA STORAGE
TOPSIDE SOUNDER	20.0/9.0	35.0	700	5×10^4	0.02	(a)	FLOWN (S/C); MAJOR MODIFICATION	HIGH	ANTENNAS, POWER, DATA	REQUIRES DATA STORAGE
PHOTOELECTRON SPECTROMETER										

(a) ON BOARD STORAGE READ OUT AT AVAILABLE BIT RATE.

☆ GPO 790-936

SUMMARY MINUTES

PIONEER VENUS SCIENCE STEERING GROUP
(MEETING NO. II)

DATE: March 29 and 30, 1972

PLACE: NASA - Ames Research Center
Moffett Field, California

PRESENT:

Chairman:		R. Fellows
Co-Chairmen:		S. Bauer L. Colin
Member:		J. Blamont J. Gille R. Goody D. Hunten A. Nagy G. Pettengill C. Russell A. Seiff N. Spencer U. Von Zahn J. Weinman
NASA Hqtrs:		D. Herman
Project Staff Members:		T. Canning R. Christiansen J. Sperans L. Polaski R. Nunamaker T. Grant R. Jackson

ABSENT: A. Kliore
I. Shapiro

CONTENTS:

A. First SSG Meeting Action Items

B. Reports

B.1 Pioneer Venus Project Reports
B.2 SSG Subgroup Reports

C. General Discussion

D. Second SSG Meeting Action Items

PIONEER VENUS SCIENCE STEERING GROUP
(MEETING NO. II)

A. First SSG Meeting Action Items.

I.1 Conflict-of-Interest Considerations. - This item was closed with the following statement by Dr. Fellows.

"There will be no contacts between the SSG members and potential Pioneer Venus study contractors until after May 1, 1972. After that date, all such contacts shall be made with the cognizance of the ARC Pioneer Venus Project Office."

Dr. Fellows also distributed copies of the following NASA document for general guidance in the area of consultation:

"Standards of Conduct for Special Government Employees - Advisers, Consultants, Experts," NHB 1900.2A dated October 1967.

I.2 Arecibo - possible role for 76/77 probe mission. - Dr. Fellows reported that Arecibo could be made available for use on these missions. It was generally agreed that Arecibo not be considered as a primary communication link with the probes. It should, however, be considered as an enhancement to the DSN stations. New action item II.1 is intended to close this item.

I.3 SSG request for briefing on Mariner Venus '73 Mission (MVM). - Dr. James Dunn, JPL Project Scientist for MVM, gave a presentation on the MVM mission parameters and a brief description of the instruments to be flown. He noted that the mission trajectory and the instruments design are optimized for the Mercury encounter.

I.4 Obtain contents or summary of the Donahue Space Science Board Study on Venera missions to Venus. - This is still open or is now designated as new action item II.2.

I.5 Report on use of Very Long Baseline Interferometry Techniques in Conjunction with Probe Mission. - Dr. Pettengill presented the highlights of a written report being prepared by Dr. Shapiro. The action item for this written report is now designated II.3.

I.6 Report on "geoscience" Implications of Magnetometer Experiments from Orbiter and Spacecraft. - Dr. Russell distributed a report entitled, "Arguments for a Flyby of the Pioneer-Venus Bus" to close out this action.

First SSG Meeting Action Items (Continued)

I.7 Report on Use and Value of Magnetometers in Atmospheric Probes - Dr. Russell distributed a report entitled, "Pioneer Venus Magnetometer Requirements," to close out this action.

I.8 Report on Present Status of Mass Spectrometry for Main Probe Experiments, i.e., Present Capability, Development Needs, Work Underway, Etc. - During the Atmospheric Structure Subgroup Meeting, Mr. Spencer described the mass spectrometry development presently being pursued at GSFC.

I.9 It was recommended that Leovy, Lewis, and Donahue be contacted as to their interests in participating at a future meeting as consultants. (Fellows) - This item is still open and is new action item II.4.

I.10 The project staff will identify possible candidate experiments for consideration by the SSG. - Mr. Sperans distributed several handouts describing some candidate experiments. The SSG recommendations on continuing development of these are noted in the main body of the meeting minutes.

I.11 The project staff will obtain more information on (a), Can the miniprobe heat shield be discarded following entry? (b), What consideration is being given to heated windows on the main probe? (c), Can the bus be put into a flyby trajectory after probe release?

(a) This question was discussed by Mr. Canning. Further studies in this area will be part of new action item II.5.

(b) The general problem of window design was discussed by Mr. Canning. Further studies in this area will be part of new action item II.6.

(c) Mr. Jackson distributed a report entitled, "Bus Flyby Study for 1976/77 Venus Pioneer Probe Mission," to close out this action.

I.12 German Ground Radio Station. - Dr. Bauer gave a brief report of the capabilities of this station.

First SSG Meeting Action Items (Continued)

B. Reports.

B.1 The Ames Pioneer - Venus Project Team presented the following reports in addition to those previously mentioned as responses to action items:

1. Tracking and Data - Mr. Grant discussed the communications capability and constraints for the probes and the probe bus. He emphasized the major area of uncertainty in the present analysis is the loss due to atmospheric turbulence. Mr. Grant also discussed the tradeoffs that can be made between the data rates, the bit error rates and the coding system options. Also discussed were the problems associated with use of a transponder on the small probes for doppler tracking. New action Item II.7 resulted from the above discussions.

2. Entry Probes - Mr. Canning discussed the aerodynamic design of the probes. He also narrated a short movie that demonstrated the stability of a "burbled" sphere. New action item II.8 resulted from this presentation.

3. Spacecraft Magnetic Cleanliness - Mr. Christiansen distributed a report entitled, "Considerations Relating to Spacecraft Magnetic Cleanliness." A discussion of the report resulted in the generation of new action item II.9.

B.2 The SSG Subgroups presented the following reports:

1. Cloud Experiments - Dr. Gille reported that the following questions must be answered in order to determine the nature of the cloud structure:

   a. Where are the clouds? Are they layered? How thick are they?

   b. Are the clouds condensibles or noncondensibles?

   c. What is the radiative heat budget as a function of altitude?

   Dr. Gille described the "Kyle Boiler" and suggested its possible use in detecting aerosols. New action item II.10 resulted.

Dr. Weinman mentioned an analyzer that was suggested by Dr. Turkevitch of the University of Chicago. It would determine the composition of particles and/or aerosols that had impinged on its detector surface.

Hygrometers were also discussed. Since H_2O would be detected by the mass spectrometer, a firm need for this instrument was not established. However, no objections would be raised against conducting some tests to determine if a hygrometer exists that would only detect H_2O.

2. Atmospheric Structure - Dr. Hunten briefly discussed the problems associated with designing a mass spectrometer for the large probe. A mass spec inlet design proposed by GSFC was described. A revised weight and power estimate for the mass spec was also given.

   Dr. Hunten also presented the results of the subgroups review of several of the candidate experiments compiled by Mr. Sperans. It was noted that more detailed information was required on several of the experiments before firm conclusions could be drawn.

   Dr. Von Zahn suggested that this subgroup also investigate alternate approaches to determining the atmospheric composition.

3. Miniprobe - Dr. Goody authored the scientific requirements of the miniprobes and the design problems associated with them. New action items II.5, II.6, II.7, II.8 and II.9 address these problems.

C. General Discussions.

C.1 Model Atmosphere - Following a brief discussion on model atmospheres, Dr. Goody requested the Project Office provide a "strawman" for the SSG to critique. Dr. Colin indicated that the GSFC model 3609 was the projects' choice for the RFP. However, the project was awaiting the release of a new study on the Venus atmosphere being prepared by Aerospace Engineering Associates in Cambridge, Massachussetts. (Dr. Mc Elroy is being used as a consultant). Dr. Bauer indicated that the first draft is ready for review. Dr. Goody requested an attempt be made to expedite the study's release. New action item II.11 resulted from this discussion.

First SSG Meeting Action Items (Continued)

C.2 Format of SSG Final Report - Dr. Colin presented a suggested outline for the SSG Final Report as a means of structuring SSG deliberations in remaining meetings. During the discussion that followed, it was generally accepted as covering all of the essential items.

The first item, Scientific Objectives, was viewed as the vehicle for reiterating the importance of and reasons for Venus exploration. At Dr. Fellows' suggestion, Dr. Goody agreed to take the lead in preparing this section. He did, however, request Dr. Pettengill to assume the chairmanship of the miniprobe subgroup. He further requested that the project office provide assistance in researching the necessary background data. Dr. Colin agreed to coordinate this effort. Dr. Bauer also volunteered the services of GSFC to assist in this area as well. New Action Item II.12 resulted.

On another item, Candidate Payloads, Dr. Goody suggested that several payloads, based on a different total weight limits, be defined for each vehicle. No objections were voiced to this suggestion.

On the subject of early scientific instrument development and tests, the SSG agreed that their recommendations indeed belong in the final report. However, they urged the Project Office to identify the critical items and to initiate studies as soon as possible. R. Fellows and D. Herman both agreed that FY '72 project funds earmarked for this prupose could now be committed. (New action item II.13).

C.3 Completion date for SSG Final Report - It was asked if the SSG Final Report could be delayed until after the entry of Venera 8. Mr. Herman noted that the report must be completed on time to permit it to be presented to the Space Science Board in July. This presentation is necessary to get the SSB endorsement of the program to the NASA Administrator by August 1.

C.4 SSG/Project Office Interactions - During the course of the meeting the SSG members made it clear that the Project Office could and should freely consult with the SSG members.

C.5 A bus and orbiter subcommittee was formed consisting of A. Nagy as chairman, C. Russell, A. Kliore, G. Pettengill, J. Gille.

D. <u>Second SSG Meeting Action Items</u>.

II.1 The Pioneer Venus Project is to prepare a statement on the project's requirement for Aricebo. (R. Nunamaker)

II.2 Obtain contents or summary of the Donahue Space Science Board Study on Venera missions to Venus. (R. Fellows)

II.3 Report on use of Very Long Baseline Interferometry techniques in conjunction with probe missions. (I. Shapiro)

II.4 It was recommended that Leovy, Lewis and Donahue be contacted as to their interests in participating at a future meeting as consultants. (R. Fellows)

II.5 The Pioneer Venus Project is to perform a feasibility study for downward optical viewing from the small probe. Included is an investigation of discarding the heat shield after entry. (T. Canning)

II.6 The Pioneer Venus Project is to study the problems associated with penetrations through the probe shell. These penetrations will include instrument windows, the mass spectrometer inlet, temperature and pressure probes and electrical connectors. (T. Canning)

II.7 The Pioneer Venus Project is to perform a feasibility study to determine coherent vs. noncoherent tracking coverage tradeoffs for the small probes. (T. Grant)

II.8 The Pioneer Venus Project is to perform entry trajectory studies based on different models for Venus winds. (~~[illegible]~~) T. CANNING

II.9 The Pioneer Venus Project is to identify the interface problems and cost impact of magnetometers on the probes and probe bus.

II.10 Conduct further analysis on the operation of the "Kyle Boiler" and determine the applicability of it for Venus atmosphere measurements. (J. Gille)

II.11 The Pioneer Venus Project is to provide a model atmosphere for use by the SSG. This model should include the study being conducted by Aerospace Engineering Assoc. (L. Colin and S. Bauer)

II.12 The Pioneer Venus Project is to provide an evaluation of the USSR versus the USA space instrumentation capabilities as related to Venus exploration. (L. Colin)

II.13 The Pioneer Venus Project is to identify critical scientific instruments and/or concepts which require "long lead development and/or study." Appropriate studies will be initiated. The Project will provide to the SSG Continuing Progress Reports. (J. Sperans)

SUMMARY MINUTES
(with corrections of 6-5-72)
PIONEER VENUS SCIENCE STEERING GROUP

(MEETING NO. III)

DATE: April 24 and 25, 1972

PLACE: NASA-Ames Research Center
Moffett Field, California

PRESENT:

Chairman:	R. Fellows	
Co-Chairman:	L. Colin	
Members:	J. Blamont J. Gille R. Goody D. Hunten A. Kliore A. Nagy G. Pettengill C. Russell A. Seiff N. Spencer U. von Zahn J. Weinman	
NASA Hqrts:	D. Herman L. Jones R. Kraemer I. Rasool	
ESRO Representatives:	M. Ackerman R. Pacault	

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A. Second SSG Meeting Action Item Responses

B. General Discussion

C. Sub Group Reports

D. Third SSG Meeting Action Items

A. Second SSG Meeting Action Item Responses

ACTION ITEM: (II.1)

The Pioneer Venus Project Office is to prepare a statement on the project's requirement for Aricebo. (R. Nunamaker)

RESPONSE:

The following compares the primary characteristics of the Arecibo Observatory with a typical 64 meter antenna:

	ARECIBO (305 meter)	DSN (64 meter)
Antenna Gain (S-Band)	72 dB	61 dB
Pointing Angle from Zenith	±20°	±80-85°
Viewing Period	2.3 hr.	Continuous

These characteristics are projected for the Pioneer Venus time period because presently Arecibo has not been converted to S-Band and the additional DSN 64 meter antennas have not been completed to allow continuous coverage.

The Arecibo Observatory, while providing a 10-11 dB gain in the communications down link, is not an operational facility. It, therefore, cannot be considered as a Project requirement for mission planning except where it might be used to enhance the mission objectives. The entire mission sequence with the required factors of safety must be designed assuming the DSN 64 meter coverage as prime.

The Arecibo Observatory was initially investigated in relationship with the Pioneer Venus Orbiter mission. Enhancement of the objectives of this mission could be beneficial under certain circumstances, e.g., after the spacecraft has been placed in planetary orbit and the spacecraft system considered healthy, short periods of time could be selected for increasing the data rate during an Arecibo coverage period. Anytime Arecibo is used, real time data for mission control would be lost.

Prime support of the probe missions during entry cannot be considered except to enhance the data retreival or provide an extreme tolerance for contingency capability if entry is much more adverse than that estimated.

The midcourse maneuvers could be planned and executed to allow the important entry sequence to occur during the overlap of the DSN 64 meter antennas of Goldstone, California and Madrid, Spain, which in turn would provide for Arecibo coverage for enhancement only.

ACTION ITEM: (II.1) Continued

In keeping with the low cost aspects of this program, the Pioneer Venus Project cannot entertain the idea of developing this requirement, if significant Project funds are needed. If arrangements can be made to acquire this support at basically no cost to the mission it makes sense to do so. Costs of providing recording equipment, ground communication links, and training of station personnel must all be considered in light of the low priority of this possible support requirement.

Requirements of this type are documented in the Project Support Instrumentation Requirements Document (SIRD) whereupon, they are reviewed in detail by NASA Headquarters. This will be done by the project when that document is prepared, clearly defining this requirement as a low priority item, not to be supported by any significant project funding. Mission data rates will be designed for the DSN 64 meter antenna network system.

ACTION ITEM: (II.2)

Obtain contents or summary of the Donahue Space Science Board Study on Venera missions to Venus. (R. Fellows)

RESPONSE:

Dr. Goody stated that this study had a "Restricted" classification that has now been removed. His copy is so marked and therefore is unable to distribute it. He feels that copies can now be obtained from the NAS. The action remains on R. Fellows to obtain copies.

ACTION ITEM: (II.3)

Report on use of Very Long Baseline Interferometry techniques in conjunction with probe missions. (I. Shapiro)

RESPONSE:

The following report was presented for Dr. Shapiro by Dr. Pettengill:

Shapiro has completed 1st order error analysis of case where 4 probes are observed by η "well-separated," i.e., long-baseline, Earth-based receiving stations.

Minimum number of stations is $\eta = 3$ to determine both East-West and North-South angular components. For redundancy, $\eta = 4$ would be preferable (a suggested set which satisfies the geometric constraints rather well comprises: Madrid and Goldstone DSN station, together with Arecibo and Haystack Observatories). It is assumed that Hyrdogen Masers would be available at each of the observing sites for accurate frequency reference.

Analysis indicates that at least one of the probes (or bus, if that will remain operative and in view throughout entry period of probes) should have an accurately known frequency, i.e., a transponder. Again, for redundancy, it is suggested that a transponder be placed on board the main probe and that a trajectory be used for the bus which allows it to remain in view of the Earth-based antennas as long as possible during the probes' entry.

It would appear that if the frequency emitted by the mini-probes can be specified to a fractional accuracy of between 10^{-7} and 10^{-8}, the major objectives of wind measurement can be met. It is in this area that further, second-order, error analysis is needed. Shapiro is attempting this analysis and a written report will be available before the June SSG meeting.

<u>ACTION ITEM:</u> (II.4)

It was recommended that Leovy, Lewis and Donahue be contacted as to their interests in participating at a future meeting as consultants.
(R. Fellows)

<u>RESPONSE</u>:

This item remains open.

ACTION ITEM: (II.5)

The Pioneer Venus Project is to perform a feasibility study for downward optical viewing from the small probe. Included is an investigation of discarding the heat shield after entry. (T. Canning)

RESPONSE:

Provision of forward "visibility" from the mini probe can be obtained after entry by:

a. Deployment of boom mounted sensors or windows from base region to "look around" remaining heat shield.

b. Jettisoning entire heat shield in a manner like that used for maxiprobe after deceleration.

c. Jettison plugs (shutters) in the heat shield to expose windows after deceleration.

Advantages of "a" are simplicity of concept, ease of keeping window clean during entry.

Disadvantages of "a" are long optical path for inboard sensors (or poor environment for outboard) actuation requirement after entry, sealing against environment, difficult location for "de-fogging" heater on window.

Advantages of "b" are that once this track is taken, all instrument deployments are probably simplified and window de-foggers are protected. Frontal area may be greatly reduced so as to reduce descent time - perhaps 30%. Thermal control is eased - perhaps by 2#.

Disadvantages of "b" are complex separation, actuators, and ejection system. A weight penalty of over 4# for a parachute or about 2# for a mortar or pyrotechnic ejection would probably more than offset thermal system weight reduction.

Advantages of "c" are relative simplicity and positive action. If small shutters built into heat shield - aeroshell and forced open by pyro actuators each aperture can be opened for less than 1/2#, perhaps 1/4# , as was done for PAET thermocouple. Good optical efficiency and minimum design impact are features.

Disadvantages of "c" are that the window would be recessed and would be prone to dust and condensate collection.

These factors will be studied in greater detail throughout the consideration of downward looking mini probe instruments by Tom Canning and Nick Vojvodich.

ACTION ITEM: (II.6)

The Pioneer Venus Project is to study the problems associated with penetrations through the probe shell. These penetrations will include instrument windows, the mass spectrometer inlet, temperature and pressure probes and electrical connectors. (T. Canning)

RESPONSE:

The power required to combat window fogging on the initially cold capsule windows was evaluated briefly by calculating the heater power necessary to raise the temperature of the outer window in a double-glazed installation slightly faster than the ambient temperature is raised. The power applied must slightly exceed the sum of that required to store energy in the pane and that required to overcome conduction losses into the window frame.

q stored = Heat capacity X temperature rise rate

q frame = Conductance X temperature difference + heat capacity X temperature rise rate

At parachute release, a 2.5 cm window, 1 cm thick, requires about 2 watts for storage and 3 watts for frame losses.

A study of alternative designs to reduce this severe penalty is being pursued. An elaborate design which may reduce the required power to less than 1 watt is being studied to obtain a quick assessment of the prospects for low power.

Thermal Penetrations

Heat conduction through typical installations which must penetrate the insulation will be assessed for each penetration and, in effect, "charged" to the instrument or function which it serves.

ACTION ITEM: (II.7)

The Pioneer Venus Project is to perform a feasibility study to determine coherent vs. non-coherent tracking coverage tradeoffs for the small probes. (T. Grant)

RESPONSE:

It is not clear from the action item statement wether it refers to study of coherent vs. non-coherent telemetry or one-way vs. two-way tracking from the small probes. However, studies have been initiated relative to both questions. These studies require some complex analysis and computer simulation work and will not result in accurate tradeoff information for 6 months or more.

ACTION ITEM: (II.7) Continued

Central to both questions is the requirement to derive a realistic, quantitative model of the effect of turbulence on the telemetry signal. Several approaches have been taken to that problem:

A study to estimate the spectral shape of the phase and amplitude noise on the signal due to turbulence is being initiated by Richard Woo at JPL. Support has been requested of Dr. Goldstein at JPL to estimate a bound on turbulence induced spectral line spread based on his radar mapping of Venus this June. Further information on the characteristics of Venera 7 data is being gathered. In addition, a study is being negotiated with Dr. Eshleman at Stanford to look at the overall characteristics of Venus atmospheric losses and estimate the effects of high zenith angles on the telemetry signal.

With regard to the study of coherent vs. non-coherent telemetry, a simulation study is being initiated by James Springett, at JPL. This study will derive performance measurements of coherent and non-coherent coded modulation as a function of perturbation parameters representing models of the turbulence effect.

With regard to the feasibility of one-way vs. two-way doppler tracking, both a transponder and a very stable oscillator (for one-way doppler) is being considered. Enough development has already been done on the transponder to establish its constraints. On the other hand, a stable oscillator design is currently being studied by the Applied Physics Laboratory, under our direction.

ACTION ITEM: (II.8)

The Pioneer Venus Project is to perform entry trajectory studies based on different models for Venus winds. (T. Canning)

RESPONSE:

Effects of Atmospheric Motion on Probe Descent

a. Steady winds are the simplest atmospheric motions in terms of flight influence. Horizontal wind components simply introduce lateral translation of the probe but have no effect on descent or stability. Vertical wind components add directly to the descent velocity, so the altitude history is directly influenced.

b.* A steady wind shear (constant derivative of horizontal wind speed with respect to vertical distance traveled) introduces a very small inclination of the descending system and is most severe for a parachute - suspended capsule. The inclination, α, can be approximated by:

* The analysis in this paragraph is over-simplified. More defensible results, arriving at the same conclusion, have been added to this series of action items.

ORIGINAL PAGE IS OF POOR QUALITY

ACTION ITEM: (II.8) Continued

$$\alpha = \frac{1}{2\, mg_{♀}} \rho_\infty \left[\frac{dW}{dZ}\right]^2 \ell^2 A\, C_n$$

where $mg_{♀}$ is the capsule weight

ρ_∞ is ambient density

$\frac{dW}{dZ}$ is the wind shear

ℓ is the distance between parachute canopy and the probe capsule

A is the capsule reference area

C_n is a non-dimensional aerodynamic coefficient

A wind shear of 10 meters/sec km would result in an inclination of about one-tenth degree.

c. The effect of a "sharp edged gust"* (horizontal wind) can be visualized by considering the response to an impulsively started wind. If we ignore the parachute mass (its own ballistic coefficient is enormously less than that of capsule), we can see that as a first approximation the first swerve will reach an inclination α of

$$\alpha = \tan^{-1} \frac{\Delta W}{U}$$

Just before parachute release $U \approx 4 \frac{M}{Sec}$ so a 1 m/s sharp-edged gust yields

$$\alpha = \tan^{-1} \frac{1}{4} \sim 15°$$

This is a violent response but is greatly modified by response of the capsule to side loads from the displaced parachute and by lateral restraint on the canopy's motion by the capsule's inertia. Clearly, the motions will not be small with this strength of disturbance. Amplitudes and damping of such systems are difficult to characterize in straightforward terms; recourse to the extensive literature on parachute development and performance is required. Early evidence suggests that systems yielding excursions less than 5° in Earth descent are easily achievable. This art will be further examined by John Givens to determine how similar performance can be attained in the atmosphere of Venus.

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* Dr. Goody felt that one should not be too concerned about any sharp-edged gust. He felt that if the parachute specifications are good for Earth they should be okay for Venus, since the Venus atmosphere is not as disturbed as the Earth's.

ADDENDUM:

A more rigorous analysis of descent through a gradual linear wind shear shows that

$$\alpha \approx \frac{A_c}{A_p} \frac{C_{Dc}}{C_{Dp}} \frac{dW}{dZ} \frac{\ell}{V}$$

α is the trim position away from vertical

Ac and Ap are areas of capsule and parachute, respectively

CDc and CDp are corresponding drag coefficients (roughly equal)

W is horizontal component of wind

Z is altitude

ℓ is shroud line length

V is descent speed

Inserting reasonable values into this expression, we get

$Ac/Ap \approx 10^{-2}$

$CDc/CDp \approx 1$

$dW/dZ \approx 0.1 \frac{m}{sec,m}$

$\ell = 10$ m

$V = 4$ m/sec

$\alpha \approx 0.15$ deg.

ACTION ITEM: (II.9)

The Pioneer Venus Project is to identify the interface problems and cost impact of magnetometers on the probes and probe bus. (R. Christiansen/J. Sperans)

RESPONSE:

Magnetometer instrument types which might be considered for the probes and probe bus have been identified and described in terms relating to the spacecraft interface. A preliminary assessment of interface complexity, system impact, and related considerations will be provided to the SSG during its third meeting.

ACTION ITEM: (II.10)

Conduct further analysis on the operation of the "Kyle Boiler" and determine the applicability of it for Venus atmosphere measurements.
(J. Gille)

RESPONSE:

Dr. Gille reported that the instrument as presently designed measures the temperature rise of a gas flowing through a heated tube (0.5 cm X 0.5 cm cross section). The instrument measures the product of the latent heat of the condensibles in the gas and the mass flow of the gas. One of the major problems with this instrument is the amount of power required for heating the tube. It is estimated that on Venus approximately 1 watt would be required in the upper atmosphere while 30 watts would be required in the lower atmosphere. Another problem is the definite possibility of ambiguous interpretation of data received.

Following a discussion, it was decided that no further investigation of the use of this instrument is desirable.

This action item is therefore considered closed.

ACTION ITEM: (II.11)

The Pioneer Venus Project is to provide a model atmosphere for use by the SSG. This model should include the study being conducted by Aerospace Engineering Associates (L. Colin).

RESPONSE:

A draft copy of the Aerospace report, excluding the atmosphere models, has been obtained and is available for review. The Aerospace people are attempting to run the models on their computer in time for the 3rd SSG Meeting.

It was agreed that A. Seiff will critique the new model atmosphere when received.

ACTION ITEM: (II.12)

The Pioneer Venus Project is to provide an evaluation of the USSR versus USA space instrumentation capabilities as related to Venus exploration (L. Colin).

RESPONSE:

A library of Russian Space Exploration has been started in order to establish a detailed history of the Venera flights. Numerous papers have been collected pertaining to the Venera 4 through Venera 7 missions. Little is known, so far, about Venera 8, except for a statement by G. I. Petrov, Director of the Soviet Institute of Space Research, who said that in addition to measurements previously made, "a few additional experiments," will be made, whose main objectives are to analyze the Venusian soil so that it can be compared with Earth soil. He said the analysis will involve bombarding the surface with radiations that can be sensed by spacecraft systems, and the resultant reaction will indicate the basic elements of the soil.

An attempt was made to launch Venera 9 (Cosmos 482) on March 27, 1972, but it failed to leave Earth orbit.

A valuable addition to any student of the Russian Space Program is the recently written Soviet Space Programs, 1966-70, Staff Report, Senate Document No. 92-51, for use of the Committee on Aeronautical and Space Sciences, United States Senate, by the Library of Congress.

An assessment of the recent Soviet Mars Missions and their relation to the U. S. Planetary Program is given in the JPL internal Report No. 201-72-1, "Considerations of the Soviet Planetary Program in Light of the Mars-2 and Mars-3 Missions," 22 February 1972.

Conversations with the JPL people indicate that they are now studying the Venera program in order to make a similar assessment as was made for the Mars missions.

Study of the Russian Space Program will be a continuing effort in order to compare their program with ours.

During the meeting, Dr. Blamont provided an ESRO literature recon on Venera for use by the Pioneer Venus Project.

ACTION ITEM: (II.13)

The Pioneer Venus Project is to identify critical scientific instruments and/or concepts which require "long lead development and/or study". Appropriate studies will be initiated. The Project will provide to the SSG continuing progress reports. (J. Sperans)

RESPONSE:

Wind-Cloud-Altitude Radar

Preliminary studies indicate feasibility of scaling down Apollo/ Surveyor type doppler radar, to fit large probe, and provide reasonably good performance in measuring probe velocity, distance to cloud layers, and probe altitude. (20 km max altitude, ± 10 cm/sec velocity accuracy, ± 100 meters altitude accuracy.)

In view of the large potential impact on probe design and program budget, a conceptual design/feasibility-verification study is needed prior to experiment selection.

An RFP for such a study has been prepared and procurement (open competition) is proceeding. Target dates:

RFP release	15 May 1972
Proposals due	5 June 1972
Contract Award	1 August 1972
First report	15 Sept. 1972

Hygrometers

At least one existing type appears capable of operating in the Venus Atmosphere and providing unambiguous measurement of water vapor content, dew point, and stratification at a cost, weight and power low enough to warrant serious interest as a complement/backup for primary instruments. (i.e.: 100 grams, 10 milliwatts.)

A modest study and test effort is required to verify performance capability and possibly compare two or more candidate units.

An RFP for feasibility tests is in preparation . Target dates:

RFP release	1 June 1972
Proposals due	20 June 1972
Contract Award	1 August 1972
First Report	1 October 1972

ACTION ITEM 11.13 (Continued)

X-Ray Fluorescence Spectrometer

A feasibility study is in progress at ARC. A preliminary report will be provided to the SSG by the June meeting.

High Temperature Components

A family of electronic components and power source capable of operation at ambient temperature in the Venus lower atmosphere ahve been identified. A feasibility study and tradeoff analysis are planned and an RFP to industry is in preparation. Target date for RFP release is 30 June 1972.

Inlet System & Interface, Mass Spectrometer

The availability of a suitable inlet system for the mass spectrometer on the large probe is considered to be a critical element in the 1976/77 multiprobe mission. ARC is forming an inlet development study team, consisting of specialists in fluid mechanics, surface chemistry and mass spectrometry and probe system engineers, to define the inlet problem, survey the current state of the art, and explore solutions. Determining the actual point of interface between project-furnished probe system and experimenter furnished mass spectrometer will largely be based on the outcome of this study. Promising inlet configurations will be modeled and tested to verify performance. Target date for preliminary report is 15 July 1972.

Nephelometer

ARC will support the fabrication and test of the nephelometer designed by Dr. Blamont to determine feasibility of such an instrument for the small probe. Specific arrangements for scientific and/or engineering support will be made with Dr. Blamont at the time of the 3rd SSG meeting, and work will begin at that time. Target date for testing an engineering model is 31 July 1972.

B. General Discussion

1. ESRO Presentation - Dr. Ackerman and Mr. Pacault presented highlights of the ESRO study for a Venus orbiter. Mr. Herman, from NASA Headquarters, described a proposed plan for NASA and ESRO to cooperatively perform the 1978 orbiter mission. This plan basically has NASA providing the spacecraft structure and basic spacecraft systems (power, communications and propulsion), the launch vehicle, and the retreval of the inflight data. ESRO would be responsible for INTEGRATING ~~providing~~ the scientific payload ~~and integrating it~~ into the spacecraft. ~~No plan has been formulated as to the relationship of the SSG to a comparable ESRO scientific group~~. It was indicated that ESRO would be unable to endorse any plan for this venture until their council meeting in March, 1973. New Action Item III.13 resulted from this discussion.

Correction 6-5-72
The responsibility for payload selection and funding has not been resolved at this time, However it is assumed that payloads would be provided by scientists from both the United States and Europe.

2. Location of Final SSG Meeting - It was decided to hold the final SSG Meeting at Ames for the week of June 5 through 9, 1972.

3. JPL Presentation - Roger Burke, JPL, addressed the SSG, on the matter of a promotional film for Pioneer Venus, similar to those done for NASA Headquarters by JPL on other programs. He showed a portion of a film made for a proposed multiple comet encounter mission as an example, and solicited comments and suggestions from the SSG.

The general reaction was that such a computer-made film, with emphasis on depicting the coupler trajectories of a cometary mission, was not really necessary to the case of the Venus missions and that an animated "cartoon" approach, showing the deployment of probes, targeting, viewing and sampling, and the entry and descent of probes would be more suitable.

4. North American Rockwell Presentation - Dr. Heide presented a detailed account of his experimental studies of atmospheric pollution in the Los Angeles area.

C. Sub-Committee Reports

Correction 6/5/72 NOTE: All categories assigned to instruments are to be considered preliminary

1. Cloud Structure Sub-Committee - The report of this committee resulted in new action items III.2, 3, 4, 5 and 6. The following instruments were designated as a candidate payload for determining cloud structure:

a. Solar flux sensor (Category I)
b. Cloud particle size analyzer (Knollenberg device) (Category I)
c. Two-channel IR radiometer (Category B)
d. Aureole Sensor (Category B II)
e. Evaporimeter/Condensiometer (Category DNC)
f. (α,γ), (α,x), (α,P) analyzers (Category DNC)

C. Sub-Committee Reports (Continued)

Category I - Primary instrument

Category B - Backup instrument - gives readings that are redundant with Category I

Category B II - Backup instrument - lower priority than B

Category DNC - Desirable instrument but no credibility established

Category II - Secondary instrument, (desirable but not absolutely necessary)

2. Large Probe Sub-Committee - The report of this committee resulted in new action items III.7, 8, 9 and 14. The following instruments were designated as a candidate payload in addition to those instruments designated by the Cloud Structure Sub-Committee:

a. Neutral Mass Spectrometer (Category I)

b. Temperature measurement (Category I)

c. Pressure measurement (Category I)

d. Accelerometers (Category I)

e. Wind-Cloud radar (Category I conditional on further study of the VLBI)

correction 6/5/72

f. Transponder (Category ~~II~~ I conditional on further study of the VLBI)

g. Hygrometer (Category II)

h. Miniseisometer (Category II)

i. Nephelometer (Blamont type) (Category B II)

j. Shock layer radiometer (Category B)

The requirement for a surface approach indicator was discussed. It was decided that such an instrument would not be required.

The requirement for a magnetometer on the large probe was discussed. It was decided that magnetometers would be carried only on the small probes.

C. Sub Committee Reports (Continued)

The bus committee also reported that they would like the bus deployment to be timed to permit the maximum overlap between the probe and the bus entries. Also under consideration, is a plan to have the first bus enter the Venus atmosphere in the same region as the large probe entry, and to have the second bus targeted for a flyby.

5. Orbiter Sub-Committee - The report of this committee resulted in new action item III.10. The following instruments were designated as the minimum payload for the orbiter:

a. Solar wind

b. Magnetometer

c. Neutral mass spectrometer

d. Low energy charged particle detector

e. Ion mass spectrometer

f. IR radiometer

g. Radar altimeter

h. Dual frequency radio propagation

The committee reported that if payload weight limits permit the following additions should be made:

i. Electric field

j. Airglow

k. The IR radiometer expanded into an IR spectrometer

The last item to be considered to be added to the payload is:

l. High energy charged particle detector

Several other instruments were discussed and were not considered necessary instruments for this mission. These were:

Correction 6/5/72
This is a bus instrument → m. Retarding potential analyzer - The committee did not feel that information to be gained from this instrument justified large data transmission requirement.

n. Microwave Radiometer - No strong justification for this instrument could be made by the meteorologists. The instrument would also require a significant portion of the payload weight.

C. Sub-Committee Reports (Continued)

o. Topside Sourder - This instrument could not be justified in view of its high weight, power, and telemetry requirements.

p. Spin Scan TV - (same as o.)

The committee also recommended that the orbiter have a periapsis latitude of 40 to 50 degrees and have the highest inclination that is consistent with the selected periapsis.

There was considerable discussion on the preferred orientation of the spacecraft's spin axis. The project stated that at the present time, it had the flexibility to design the spacecraft with its spin axis either parallel or perpendicular to the ecliptic plane. The committee's assessment of the scientific requirements indicated that they too, with the possible exception of the solar wind measurement requirement had no strong preference. It was decided to resolve this issue at the final SSG meeting. This would permit the project to review the phase B proposals for possible advantages that one orientation might offer.

D. <u>3rd SSG Meeting Action Items</u>

1. The following old action items remain open: II.2, II.3, II.4, II.5, II.6, II.7, II.8, II.9, II.11, II.12 and II.13.

2. The Pioneer Venus Project will examine the Knollenberg and Blau cloud particle imaging devices and prepare a critical report on its feasibility for use on the large probe. (J. Sperans/A. Seiff)

3. The Pioneer Venus Project will determine what materials are available for IR (10μ) windows that will not degrade in the Venus temperature, pressure and chemical environment. (T. Canning)

4. Dr. Rudolph Hanel (NASA/GSFC) is to be requested to re-examine the simple two-channel IR radiometric cloud detector for Venus. (N. Spencer)

5. The Pioneer Venus Project will assess the problems of making Venus atmosphere measurements with the Turkevitch consortium and work with them to develop a conceptual design of a practical alpha particle device to measure the composition of condensates. The sensitivity analysis will be revised where appropriate. (J. Sperans/C. Colin)

6. Discuss the alpha particle analyzer with Franzgrote (JPL). (D. Hunten/A. Kliore)

D. 3rd SSG Meeting Action Items (Continued)

7. The Pioneer Project will provide the status of the following items by or before the June SSG Meeting:

a. Nephelometer (Blamont) design

b. Probe neutral mass spectormeter (von Zahn) design

c. Information on Dr. Block's (UCSD) miniseisometer

d. Estimated weight and power requirements for probe wind-drift radar

e. Design information on the ARC X-ray analyzer

f. Hygrometer testing

g. IR radiometers (J. Pollack/R. Boese)

8. GSFC is to provide the detail design status of their approach to the probe neutral mass spectrometer. (N. Spencer)

9. Provide test data for the proposed pressure and temperature sensors to be used on the probes.
(A. Seiff)

10. The Pioneer Venus Project is to investigate the problems associated with providing an adjustable X-Band antenna on the orbiter. This antenna would be used for radar mapping.
(R. Christiansen)

11. The Pioneer Project is to estimate the minimum safe flyby altitude for the bus.
(R. Jackson)

12. The Pioneer Project is to determine the feasibility of having a meeting between the potential phase B contractors and selected SSG members to exchange technical information.
(R. Nunamaker)

13. NASA Headquarters is to formally request the Pioneer Venus Project to prepare a revised description of the orbiter based on the phase B proposals by July 1, 1972.
(D. Herman)

14. Review the scientific requirements for the probe wind-drift radar.
(J. Gille, R. Goody, J. Weinman)

15. Prepare a detailed outline of the SSG final report and distribute to SSG members prior to June Meeting.
(L. Colin)

SUMMARY MINUTES

PIONEER VENUS SCIENCE STEERING GROUP
(Meeting No. IV)

DATE: June 5 through 9, 1972

PLACE: NASA-Ames Research Center
Moffett Field, California

PRESENT:

CHAIRMAN: R. Fellows

CO-CHAIRMAN: S. Bauer
L. Colin

MEMBERS: J. Blamont
J. Gille
R. Goody
D. Hunten
A. Kliore
A. Nagy
G. Pettengill
C. Russell
A. Seiff
N. Spencer
U. von Zahn
J. Weinman

NASA HQRS: D. Herman
I. Rasool

ESRO: M. Ackerman
G. M. Israel

PROJECT STAFF: T. Canning
R. Christiansen
T. Grant
R. Jackson
R. Nunamaker
L. Polaski
S. Sommer
J. Sperans
N. Vojvodich

C O N T E N T S

A. THIRD SSG MEETING ACTION ITEMS

All action items generated at or carried over from the third meeting were closed. This data is presented as part of the complete summary of all action items generated during the existence of the SSG.

B. REPORTS

Reports were presented by the chairman of the various subgroups of the SSG. The information contained in these reports is included in the final SSG report.

C. GENERAL DISCUSSION

C.1 Dr. Rasool reported on the discussions between the U. S. and the U.S.S.R. that took place during the recent COSPAR Meeting in Madrid, Spain.

SUMMARY OF SSG ACTION ITEMS

The following action items are listed in the general order in which they were completed and not necessarily in the order that they were generated. All positive responses to these action items are included.

1. Conflict-of-Interest Considerations for SSG Members. (Generated 3-7-72)

RESPONSE: (3-29-72 by R. Fellows)

"There will be no contacts between the SSG members and potential Pioneer Venus study contractors until after May 1, 1972. After that date, all such contacts shall be made with the cognizance of the ARC Pioneer Venus Project Office."

Dr. Fellows also distributed copies of the following NASA document for general guidance in the area of consultation:

"Standards of Conduct for Special Government Employees - Advisers, Consultants, Experts," NHB 1900.2A dated October 1967.

2. Arecibo - possible role for 76/77 probe mission.
(Generated 3-7-72)

RESPONSE: (3-29-72 by R. Fellows)

Arecibo could be made available for use on these missions. It was generally agreed that Arecibo not be considered as a primary communication link with the probes. It should, however, be considered as an enhancement to the DSN stations.

3. Arecibo - The Pioneer Venus Project Office is to prepare a statement on the project's requirement for Aricebo. (Generated 3-29-72)

RESPONSE: (4-24-72 by R. Nunamaker)

The following compares the primary characteristics of the Arecibo Observatory with a typical 64 meter antenna:

	ARECIBO (305 meter)	DSN (64 meter)
Antenna Gain (S-Band)	72 dB	61 dB
Pointing Angle from Zenith	±20°	±80-85°
Viewing Period	2.3 hr.	Continuous

These characteristics are projected for the Pioneer Venus time period because presently Arecibo has not been converted to S-Band and the additional DSN 64 meter antennas have not been completed to allow continuous coverage.

The Arecibo Observatory, while providing a 10-11 dB gain in the communications down link, is not an operational facility. It, therefore, cannot be considered as a Project requirement for mission planning except where it might be used to enhance the mission objectives. The entire mission sequence with the required factors of safety must be designed assuming the DSN 64 meter coverage as prime.

The Arecibo Observatory was initially investigated in relationship with the Pioneer Venus Orbiter mission. Enhancement of the objectives of this mission could be beneficial under certain circumstances, e.g., after the spacecraft has been placed in planetary orbit and the spacecraft system considered healthy, short periods of time could be selected for increasing the data rate during an Arecibo coverage period. Anytime Arecibo is used, real time data for mission control would be lost.

Prime support of the probe missions during entry cannot be considered except to enhance the data retreival or provide an extreme tolerance for contingency capability if entry is much more adverse than that estimated.

The midcourse maneuvers could be planned and executed to allow the important entry sequence to occur during the overlap of the DSN 64 meter antennas of Goldstone, California and Madrid, Spain, which in turn would provide for Arecibo coverage for enhancement only.

3. (Continued)

In keeping with the low cost aspects of this program, the Pioneer Venus Project cannot entertain the idea of developing this requirement, if significant Project funds are needed. If arrangements can be made to acquire this support at basically no cost to the mission it makes sense to do so. Costs of providing recording equipment, ground communication links, and training of station personnel must all be considered in light of the low priority of this possible support requirement.

Requirements of this type are documented in the Project Support Instrumentation Requirements Document (SIRD) whereupon, they are reviewed in detail by NASA Headquarters. This will be done by the project when that document is prepared, clearly defining this requirement as a low priority item, not to be supported by any significant project funding. Mission data rates will be designed for the DSN 64 meter antenna network system.

4. German Ground Radio Station Capabilities.
(Generated 3-29-72)

<u>RESPONSE</u>: (3-29-72 by Dr. Bauer)

Dr. Bauer gave a biref report on the capabilities of this station.

5. Request briefing on Mariner Venus Mercury '73 Mission. (Generated 3-7-72)

RESPONSE: (3-29-72)

Dr. James Dunn, JPL Project Scientist for MVM, gave a presentation on the MVM mission parameters and a brief description of the instruments to be flown. He noted that the mission trajectory and the instruments design are optimized for the Mercury encounter.

6. Obtain contents or summary of the Donahue Space Science Board Study on Venera missions to Venus.
(Generated 3-7-72)

RESPONSE: (4-24-72)

Dr. Goody stated that this study had a "Restricted" classification that has now been removed. His copy is so marked and therefore is unable to distribute it. He feels that copies can now be obtained from the NAS. The action remains on R. Fellows to obtain copies.

RESPONSE: (6-5-72)

The report was distributed to the SSG Members. Dr. Goody gave some brief comments on the report.

THE EFFECT OF VENERA 7 ON THE PLANETARY EXPLORER MISSIONS

This report reaffirms previous Space Science Board recommendations that exploration of Venus should be an objective of the highest priority in the United States space program in spite of the recent success of Venera 7 and the demonstrated Soviet capabilities at Venus.

In 1970 the Space Science Board conducted a study of the potential of a systematic and intensive program to explore Venus based on Explorer spacecraft technology. The study found that Venus should be an object of the highest priority for planetary science in the United States space program. These recommendations were endorsed by the Woods Hole Priorities Study of 1970. The intensive Venus program based on the Planetary Explorer concept was listed as being of the very highest priority and thus a recommended program at all budget levels.

The Space Science Board has now asked a panel consisting mostly of individuals who were Working Group leaders for the Venus study to reconsider these findings. This request comes in the light of the success of another Soviet Venera probe, which this time actually reached the planet's surface. The Panel has been asked to address itself to two specific questions:

> Do the results obtained by Venera 7 in any way alter the program of study recommended in the 1970 Space Science Board report?

Has this Soviet success demonstrated a capacity and a will for Venus exploration in the Soviet space program strong enough to warrant leaving Venus to the Russians while the United States more intensively develops other space programs?

Our answers to both questions are "no". The Planetary Explorer program recommended in the Venus study would be a well-articulated, intensive study of the planet designed to attempt to answer a list of first-order questions. Among these are the number, thickness, and composition of the cloud layers; the nature of the circulation; explanation of the high surface temperature; the reason for the lack of water and the remarkable stability of the CO_2 atmosphere; the nature of the interaction of the polar wind with the planet; the elemental composition of the surface; the distribution of mass and magnetic field strength; and the measurement of seismic activity. Venera 7 was a highly specialized probe designed to perform only two functions--to measure atmospheric temperature and pressure down to the surface of Venus. It succeeded in obtaining the temperature and confirmed the most widely held expectation--that the surface temperature is high. It has in no way changed the conditions on which the Venus study was based or answered any of the questions that Planetary Explorers are designed to answer. We can find no reason, therefore, to recommend changes in the scientific objectives set forth in previous Board studies.

The Planetary Explorer program for Venus, as set forth in the 1970 study, is a scientifically sound and sophisticated undertaking for which the required technological base appears to be available in the United States. We have no way of knowing whether the Soviets have the inclination to carry out such missions or whether they have the capability of doing so. The technology exhibited in the Venera series is not relevant to this question, being limited in its goals by comparison with the Planetary Explorer. Hence there is no compelling reason for the United States to abandon Venus and the Planetary Explorer program with the expectation that the Soviet Union would take them over.

We therefore urge that NASA follow the recommendations of the 1970 Space Science Board Study as contained in the report entitled Venus: Strategy for Exploration.

Space Science Board
January 18, 1972

7. Report on use of Very Long Baseline Interferometry techniques in conjunction with probe missions.
(Generated 3-7-72)

<u>RESPONSE</u>: (3-29-72)

Dr. Pettengill presented the highlights of a written report being prepared by Dr. Shapiro.

<u>RESPONSE</u>: (4-24-72)

The following report was presented for Dr. Shapiro by Dr. Pettengill:

Shapiro has completed 1st order error analysis of case where 4 probes are observed by η "well-separated," i.e., long-baseline, Earth-based receiving stations.

Minimum number of stations is $\eta = 3$ to determine both East-West and North-South angular components. For redundancy, $\eta = 4$ would be preferable (a suggested set which satisfies the geometric constraints rather well comprises: Madrid and Goldstone DSN station, together with Arecibo and Haystack Observatories). It is assumed that Hyrdogen Masers would be available at each of the observing sites for accurate frequency reference.

Analysis indicates that at least one of the probes (or bus, if that will remain operative and in view throughout entry period of probes) should have an accurately known frequency, i.e., a transponder. Again, for redundancy, it is suggested that a transponder be placed on board the main probe and that a trajectory be used for the bus which allows it to remain in view of the Earth-based antennas as long as possible during the probes' entry.

It would appear that if the frequency emitted by the mini-probes can be specified to a fractional accuracy of between 10^{-7} and 10^{-8}, the major objectives of wind measurement can be met. It is in this area that further second-order, error analysis is needed. Shapiro is attempting this analysis and a written report will be available before the June SSG meeting.

<u>RESPONSE</u>: (6-5-72)

Dr. Shapiro's report was distributed to the members of the SSG. Dr. Pettengill offered biref comments on the highlights of the report.

May 1972

Wind Speeds in Lower Atmosphere of Venus: Status Report on Possible Measurement Via Differential VLBI Tracking of Entry Probes

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Abstract

The potential of very-long-baseline interferometry (VLBI) is examined for use in the determination of wind speeds in Venus' lower atmosphere via the differential tracking of entry probes. A simplified mathematical model is presented in detail. An incomplete error analysis based on this model permits an educated guess to be made: An uncertainty in wind speed determination of no more than about $100t^{-1}$ m/sec, where $t>1$ is the corresponding time resolution in seconds, is an achievable goal -- without the use of transponders on the miniprobes. Certain important issues raised in the report must be resolved before firm conclusions can be drawn. However, if transponders are available on all probes, there should be little difficulty in estimating wind speeds with useful precision.

(Prepared for the Pioneer-Venus Science Steering Group)

Table of Contents

I. Introduction

Can the Venus entry probes be tracked via differential very-long-baseline interferometry (VLBI) with sufficient accuracy to yield useful estimates of the wind speeds in Venus' lower atmosphere? A definitive answer cannot yet be given. The current status of the analysis is summarized in this report with special emphasis on the main areas of uncertainty. Section II contains a brief description of the basic method, with a mathematical model and first-order error analysis being developed in Sections III and IV, respectively. The main conclusions and the requirements for additional analysis are presented in Section V.

II. Differential VLBI

The VLBI technique has been used successfully for the past five years primarily to study the structures and positions of compact extragalactic radio sources. For a strong source, the main limitations on the accuracy achievable in determining the direction to the source are the result of (i) instabilities in the frequency standard used at the observing sites, and (ii) phase fluctuations of the signals introduced by the propagation medium, mainly the earth's atmosphere and ionosphere. If several objects in nearly the same direction are observed simultaneously, these error sources can either be eliminated or drastically reduced in their effect on determinations of relative position. The frequency standard need only be sufficiently stable to allow fringes to be obtained on the strongest source which then acts as the standard for comparison with the signals from the other sources observed simultaneously. The propagation medium effects cancel to the extent that the signals from the different sources received at a given site pass through identical paths in the earth's atmosphere and ionosphere. Thus the accuracy in relative position determination can exceed that of "absolute" position determination by several orders of magnitude.

In observing the quasar 3C279, for example, our VLBI group (Whitney _et al_. 1971) discovered that its structure was consistent with a two-point-source model; these two "points" were separated by about 1.5×10^{-3} arcseconds and the standard error in the determination of the separation was only 6×10^{-6} arcseconds in the right ascension component. This extremely small error in relative position determination is meaningful because of the small angular separation of the putative two point sources and the consequent high order of cancellation of the propagation medium effects.

We call this technique of relative position determination _differential_ VLBI. We have also applied it successfully to the Apollo 16 Lunar Rover whose position relative to the Lunar Module was monitored throughout the first EVA by use of this method (Shapiro _et al_. 1972; Counselman _et al_. 1972). Although the tracking systems were far from optimally arranged for the task and although the radio frequency of the Rover differed from that of the Module by 17 MHz, the final position of the Rover calculated via the differential VLBI technique differed from the estimates of the astronauts by less than 30 m. No accurate intermediate check-points are available for comparison.

The application of differential VLBI to the tracking of the Venus entry probes differs in several important respects from the Rover-Module case. On the positive side of the ledger, we have the possibilities (i) to choose nearly identical entry probe transmitter frequencies ($\Delta f \leq 50\,kHz$) to insure that if the different signals pass through the same plasma environment, the latter's effect on phase path will cancel upon differencing; (ii) to design the receiver equipment so that at a given site the local-oscillator signals introduce the same phase noise when mixing with each of the probe signals (the commonality implies that this source of noise will also cancel upon differencing); (iii) to utilize a phase-coherent transponder on at least one of the entry probes; and (iv) to select earth-tracking sites with greater east-west and north-south baseline components. The negative side of the ledger contains more entries: (i) Venus will be about 200 times further away than the moon, causing a corresponding reduction in the accuracy of determination of the projected distance between tracked objects; (ii) the interplanetary medium has a much greater influence on Venus-earth than on moon-earth signals; (iii) Venus has an ionosphere and a thick atmosphere; the moon has virtually none of either; (iv) the tracked Venus probes will move relatively unconstrained through a fluid; the Rover was constrained to adhere to the lunar surface and hence the intrinsic two-dimensional differential VLBI tracking result could be converted to three-dimensional relative position by use of lunar topographic data; (v) the separation between Rover and Module was known at the start of the VLBI tracking period; for the entry probes corresponding information will probably not be available and thus in the latter case only the monitoring of changes in the (projected) separations of the probes, i.e. only the monitoring of (projected) velocity differences, will be possible; and (vi) the thermal environment of the entry probes will be far less stable than for the Rover and Module thus tending to cause greater variations in the transmitter frequencies of the probes.

How does the differential VLBI technique compare with the straightforward use of a turnaround transponder? In fact, they are complementary: the transponder supplies the <u>radial</u> velocity and VLBI the <u>transverse</u> components of the velocity.* The VLBI approach can be used with either a transponder or a free-running oscillator to determine the transverse components; the radial component cannot be usefully inferred without a transponder unless the <u>a priori</u> knowledge of the transmitter frequency is sufficiently accurate. For signal propagation in a vacuum , the transponder can have an enormous advantage: all other aspects being equivalent, the error in the determination of radial velocity will be less than for the differential VLBI determ-

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*By "radial" we mean parallel to the earth-Venus line.

ination of the transverse components by the ratio of the VLBI baseline to the distance from the earth to the source (i.e., by the parallax). For the Venus probes, this enormous advantage--approximately 2×10^4 in accuracy--is offset to a great extent by the systematic errors introduced by the propagation medium which largely cancel in the differential VLBI procedure. One further point needs to be made here: the differential VLBI procedure which is needed to cancel these errors yields only the relative transverse components of velocities for a pair (or more) of probes; the transponder approach yields the "absolute" radial velocity for each probe.

We may now address briefly the main problem -- the determination of the wind speeds in Venus' lower atmosphere. We distinguish two cases:

(i) Transponders Available on Entry Probes. Here we would be able to estimate usefully the velocity vector for all probes from the ordinary Doppler data. The *a priori* knowledge of both the geometry of entry and the terminal vertical velocity for each probe will most likely be of sufficient accuracy for this purpose. The (two-way) effects of the atmosphere of Venus will introduce uncertainties well below the one meter-per-second level unless the geometry is particularly unfavorable. The wind speeds will be given by the projection of the velocity vector on the plane normal to the local vertical at the probe's position. (We assume that the probe has reached "terminal" velocity in both the vertical and horizontal directions.) Under these circumstances, the VLBI measurements may not be competitive. But they will still be of interest to provide a check.

(ii) Transponders Not Available in Entry Probes. Here essentially only the pairwise differences in the probes' velocities projected on the plane normal to the earth-Venus line will be available (except in the unlikely event that the transmitter frequency of one or more of the probes is known very accurately). In general, there is difficulty in separating the contributions of the horizontal velocity components from the vertical components in the projections of the differences. If one of the tracked objects were following a ballistic trajectory (e.g., the bus on a flyby trajectory), then the contribution of the horizontal velocity component of each entry probe could be distinguished. Also, if one of the probes were directed towards the subearth point on Venus, it would be possible to identify part of the velocity projections as being due to winds. If neither of these conditions applies, it appears that models of the terminal descent and appropriate filtering would be required to extract estimates of the wind speeds. Whether such estimates would be useful has not yet been established.

From this qualitative introduction to the problems of the determination of the lower atmospheric wind speeds using differential VLBI, we proceed in the next section to the development of an appropriate mathematical model.

III. Mathematical Model

Our goal here is to develop an algorithm for the determination of wind speeds in Venus' lower atmosphere from VLBI tracking data. Let us begin with the definitions of the relevant geometric quantities. The vector distance $\vec{R}_{ip}$ from the earth-tracking station $\underline{i}$ to the entry probe p can be expressed in a geocentric reference frame as:

$$\vec{R}_{ip}(t, t-\tau_{ip}(t)) \simeq \vec{r}_{ev}(t, t-\tau_{ip}(t)) + \vec{\rho}_p(t-\tau_{ip}(t)) - \vec{r}_i(t), \qquad (1)$$

where $\vec{r}_{ev}$ is the vector distance from the center of mass of the earth to the center of mass of Venus; $\vec{\rho}_p$ is the vector from the center of mass of Venus to the pth probe, $\vec{r}_i$ is the vector from the center of mass of the earth to the ith tracking station, $\underline{t}$ is the time of reception of the signal from the jth probe at the ith tracking station, and τ_{ip} is the time delay between the transmission of a signal from the pth probe and its reception at the ith tracking station.

For the purposes of this section, we shall assume that the signals propagate in vacuum; in Section IV we will consider the medium effects explicitly. Thus, in the approximation of vacuum propagation, the phase delay $\tau_{ip}(t)$ may be found iteratively by means of a simple algorithm:

$$\tau_{ip}(t) = \lim_{n\to\infty} \tau_{ip}^{(n)}(t) \quad , \qquad (2)$$

where

$$\tau_{ip}^{(n+1)}(t) = \frac{1}{c} R_{ip}\left(t, t - \frac{1}{c} R_{ip}(t, t-\tau_{ip}^{(n)}(t))\right); \quad n = 0, 1, 2, \ldots, \qquad (3)$$

and

$$\tau_{ip}^{(0)}(t) \equiv \frac{1}{c} R_{ip}\left(t, t - \frac{1}{c} R_{ip}(t,t)\right) \qquad (4)$$

Since the velocities involved are only of the order of $10^{-4}c$, where $\underline{c}$ is the speed of light, one or two iterations will be sufficient to obtain the needed accuracy.

If we assume continuous reception of signals starting from t=0, then the phase $\phi_{ip}(t)$ of the signal received at station $\underline{i}$ from probe p may be written as

$$\phi_{ip}(t) = \phi_{ip}(0) + 2\pi \int_{-\tau_{ip}(0)}^{t-\tau_{ip}(t)} f_p(x)\, dx\,, \qquad (5)$$

where $f_p(t)$ is the frequency transmitted by probe p at time $\underline{t}$. From the measurements $\phi_{ip}(t)$ we wish to estimate the wind speeds, but in such a manner that we cancel to as high a degree as possible the adverse effects of the propagation medium (which is, however, ignored in the explicit formulation given in this section). By the formation of symmetric double differences, we can insure the tendency to cancel of any potential source of error that is common <u>either</u> to all receivers <u>or</u> to all transmitters.

Before applying this principle, we must consider a means for improvement of the estimate of $f_p(t)$ which is not known accurately <u>a priori</u>. Our results will turn out to be relatively insensitive to those estimates and so we will employ sums of the different ϕ_{ip}'s $(i = 1, 2, \ldots)$ to determine each f_p. Since f_p will vary with time in an unknown manner, we will estimate an average value $\langle f_p \rangle$ appropriate for each time resolution interval of interest. Without any important loss in generality, we may consider this interval to be a constant, T (see Section IV). Thus, we may use Eq. (5) to obtain, successively:

$$\Delta\phi_{ip}(t_{n-1}, t_n) \equiv \phi_{ip}(t_n) - \phi_{ip}(t_{n-1})$$

$$= 2\pi \int_{t_{n-1}-\tau_{ip}(t_{n-1})}^{t_n - \tau_{ip}(t_n)} f_p(x)\,dx \simeq 2\pi \int_{-\frac{T}{2}(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))}^{\frac{T}{2}(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))} f_p(y + t_{n-\frac{1}{2}} - \tau_{ip}(t_{n-\frac{1}{2}}))\,dy$$

$$\simeq 2\pi T\left(1 - \dot{\tau}_{ip}(t_{n-\frac{1}{2}})\right) \bar{f}_p(t_{n-1}, t_n), \qquad (6)$$

where

$$t_n \equiv nT \quad ; \quad n = 0, 1, 2, \ldots, \qquad (7)$$

$$t_{n-\frac{1}{2}} \equiv t_{n-1} + \frac{T}{2} \equiv t_n - \frac{T}{2}, \qquad (8)$$

$$\bar{f}_p(t_{n-1}, t_n) \equiv \frac{1}{T(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))} \int_{-\frac{T}{2}(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))}^{\frac{T}{2}(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))} f_p(y + t_{n-\frac{1}{2}} - \tau_{ip}(t_{n-\frac{1}{2}}))\,dy, \qquad (9)$$

$$\tau_{ip}(t_n) \simeq \tau_{ip}(t_{n-\frac{1}{2}}) + \dot{\tau}_{ip}(t_{n-\frac{1}{2}})\frac{T}{2}, \qquad (10)$$

and where $\dot{\tau}_{ip}(t_{n-\frac{1}{2}})$ signifies the time derivative of the phase delay evaluated at $t=t_{n-1/2}$. If the total number of tracking stations is I, then we consider

$$\langle f_p(t_{n-1}, t_n)\rangle \equiv \frac{1}{I}\sum_{i=1}^{I} \frac{\Delta\phi_{ip}(t_{n-1}, t_n)}{2\pi T(1-\dot{\tau}_{ip}(t_{n-\frac{1}{2}}))}, \qquad (11)$$

to be the average value of the transmitter frequency f_p over the corresponding receiving time interval (t_{n-1}, t_n) on the assumption that the error in the measurement $\Delta\phi_{ip}$ is independent of $\underline{i}$. If there is a dependence, a more suitable weighting function can easily be substituted. Since $\langle f_p\rangle$ depends on $\dot{\tau}_{ip}$, albeit weakly, the calculations can, and perhaps should, be repeated <u>a posteriori</u> if more precise values of $\dot{\tau}_{ip}$ become available.

We now return to the task of forming a suitable symmetric double difference. We shall use

$$\frac{1}{cT}\Delta^{2s}_{ij;pq}(t_{n-1}, t_n) \equiv \frac{\Delta\phi_{ip}(t_{n-1},t_n) - \Delta\phi_{jp}(t_{n-1},t_n)}{2\pi T\langle f_p(t_{n-1},t_n)\rangle} - \frac{\Delta\phi_{iq}(t_{n-1},t_n) - \Delta\phi_{jq}(t_{n-1},t_n)}{2\pi T\langle f_q(t_{n-1},t_n)\rangle}, \qquad (11)$$

where we defer to the following section a demonstration of the efficacy of this definition. (Here the superscript 2s denotes symmetric double difference.) From Eqs. (1)-(4), (6), and (11) we see immediately that

$$\begin{aligned}\Delta^{2s}_{ij;pq}(t_{n-1}, t_n) &\simeq cT\left[\dot{\tau}_{iq}(t_{n-\frac{1}{2}}) - \dot{\tau}_{ip}(t_{n-\frac{1}{2}}) + \dot{\tau}_{jp}(t_{n-\frac{1}{2}}) - \dot{\tau}_{jq}(t_{n-\frac{1}{2}})\right] \\ &\simeq \left(R^{(n)}_{iq} - R^{(n-1)}_{iq}\right) - \left(R^{(n)}_{ip} - R^{(n-1)}_{ip}\right) \\ &\quad + \left(R^{(n)}_{jp} - R^{(n-1)}_{jp}\right) - \left(R^{(n)}_{jq} - R^{(n-1)}_{jq}\right) \qquad (12)\end{aligned}$$

where

$$R_{ip}^{(n)} \equiv R_{ip}\left(t_n, t_n - \tau_{ip}(t_n)\right). \tag{13}$$

To discuss the implications of Eq. (12) conveniently, we shall introduce some approximations. First we introduce the vector $\vec{\rho}_{qp}$:

$$\vec{\rho}_{qp} \equiv \vec{\rho}_p - \vec{\rho}_q \quad , \tag{14}$$

which, if the time arguments coincide, represents the vector separation of probes p and q with $\vec{\rho}_{qp}$ extending from q to p. Suppressing time arguments for simplicity, we can expand R_{iq} in terms of R_{ip}:

$$\vec{R}_{iq} = \vec{R}_{ip} - \vec{\rho}_{qp} \quad , \tag{15}$$

whence

$$\begin{aligned} R_{iq} &\equiv (\vec{R}_{iq} \cdot \vec{R}_{iq})^{1/2} = (R_{ip}^2 - 2\vec{R}_{ip} \cdot \vec{\rho}_{qp} + \rho_{qp}^2)^{1/2} \\ &\simeq R_{ip} - \vec{\rho}_{qp} \cdot \hat{R}_{ip} + O\left(\frac{\rho_{qp}^2}{R_{ip}}\right) , \end{aligned} \tag{16}$$

where $\hat{x} \equiv (\vec{x}/|\vec{x}|)$ signifies a unit vector. The neglected terms in Eq. (16) will in magnitude always be less than $10^{-4}\rho_{qp}$. Using Eq. (16) in Eq. (12) yields

$$\vec{\rho}_{qp} \cdot \left(\hat{R}_{jp}^{(n)} - \hat{R}_{ip}^{(n)}\right) \simeq \vec{\rho}_{qp}^{(n-1)} \cdot \left(\hat{R}_{jp}^{(n-1)} - \hat{R}_{ip}^{(n-1)}\right) + \Delta_{ij;pq}^{25}(t_{n-1}, t_n). \tag{17}$$

By use of further approximations, the expressions for the unit vector differences can be made more perspicuous. Thus,

$$\hat{R}_{ip} \equiv \frac{\vec{r}_{ev} + \vec{\rho}_p - \vec{r}_i}{|\vec{r}_{ev} + \vec{\rho}_p - \vec{r}_i|} \quad , \tag{18}$$

and

$$\begin{aligned} |\vec{r}_{ev} + \vec{\rho}_p - \vec{r}_i|^{-1} &= \left\{ r_{ev}^2 - 2\vec{r}_{ev} \cdot (\vec{r}_i - \vec{\rho}_p) + (\vec{r}_i - \vec{\rho}_p) \cdot (\vec{r}_i - \vec{\rho}_p) \right\}^{-1/2} \\ &= r_{ev}^{-1} \left\{ 1 + \left(\frac{\vec{r}_i - \vec{\rho}_p}{r_{ev}} \right) \cdot \hat{r}_{ev} + O\left(\frac{|\vec{r}_i - \vec{\rho}_p|^2}{r_{ev}^2} \right) \right\} , \end{aligned} \tag{19}$$

whence

$$\begin{aligned} \hat{R}_{ip} &\simeq \hat{r}_{ev} \left\{ 1 + \left(\frac{\vec{r}_i - \vec{\rho}_p}{r_{ev}} \right) \cdot \hat{r}_{ev} \right\} - \left(\frac{\vec{r}_i - \vec{\rho}_p}{r_{ev}} \right) \\ &\simeq \hat{r}_{ev} - \frac{1}{r_{ev}} \left\{ (\vec{r}_i - \vec{\rho}_p) - [(\vec{r}_i - \vec{\rho}_p) \cdot \hat{r}_{ev}] \hat{r}_{ev} \right\} \\ &\simeq \hat{r}_{ev} + \frac{1}{r_{ev}} \left\{ \hat{r}_{ev} \times (\hat{r}_{ev} \times [\vec{r}_i - \vec{\rho}_r]) \right\} , \end{aligned} \tag{20}$$

where in the last line we made use of the vector identity:

$$\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c})\, \vec{b} - (\vec{a} \cdot \vec{b})\, \vec{c} . \tag{21}$$

The desired expression for the unit vector difference is therefore

$$\hat{R}_{jp} - \hat{R}_{ip} \simeq \frac{1}{r_{ev}} \hat{r}_{ev} \times (\hat{r}_{ev} \times \vec{b}_{ij}) \quad , \tag{22}$$

where

$$\vec{b}_{ij} \equiv \vec{r}_j - \vec{r}_i \tag{23}$$

is the baseline vector extending from tracking station _i_ to tracking station _j_.

What is the physical interpretation of the vector triple product appearing in Eq. (22)? It is simply the vector obtained by projecting $\vec{b}_{ij}$ onto the plane normal to $\hat{r}_{ev}$. In terms of the baseline vectors, we find by substitution of Eq. (22) into Eq. (17):

$$\vec{\rho}_{qp}^{(n)} \cdot \left[\hat{r}_{ev}^{(n)} \times \left(\hat{r}_{ev}^{(n)} \times \vec{b}_{ij}^{(n)}\right)\right] \simeq \vec{\rho}_{qp}^{(n-1)} \cdot \left[\hat{r}_{ev}^{(n-1)} \times \left(\hat{r}_{ev}^{(n-1)} \times \vec{b}_{ij}^{(n-1)}\right)\right] + r_{ev}^{(n-1)} \Delta_{ij,pq}^{2S}(t_{n-1}, t_n), \tag{24}$$

where we also neglect the very small difference between $r_{ev}^{(n)}$ and $r_{ev}^{(n-1)}$. So long as the vectors $\hat{r}_{ev} \times (\hat{r}_{ev} \times \vec{b}_{ij})$ for the different pairs (ij) are not parallel, Eq. (24) will allow the changes in the vector separation of the probes, projected onto the plane normal to the earth-Venus line, to be followed during the period of continuous tracking of the probe pairs. The actual projected vector separation, as opposed to changes in it, cannot be determined from these data alone because the initial such separation--at the time simultaneous tracking commences--is uncertain due to the fringe ambiguity. Because of the narrow band of the emissions from the probes, the projected separation of the probes will only be determined to within the equivalent of an integral number of fringes. A single fringe corresponds, for the typical VLBI baselines under consideration, to a projected distance at Venus of about 3 km. This ambiguity can be eliminated by simultaneous use of a shorter baseline interferometer pair for which the fringe spacings in the two orthogonal directions, in the plane normal to the earth-Venus line, are larger than the corresponding a priori uncertainties. This elimination is useful for establishing the geometry.

In particular, our main object is to determine wind speeds. To this end, we develop the expressions for the components of the velocity difference $\dot{\vec{\rho}}_{qp}^{(n)}$ on the plane normal to $\vec{r}_{ev}$ (a dot signifies differentiation with respect to time). For convenience, we ignore the superscript (n), assume we have a continuous determination of the projection of $\dot{\vec{\rho}}_{qp}(t)$, and define

$$\dot{\vec{\rho}}_{qp}^{\perp}(t) \equiv (\dot{\vec{\rho}}_{qp} \cdot \hat{e}_1)\hat{e}_1 + (\dot{\vec{\rho}}_{qp} \cdot \hat{e}_2)\hat{e}_2 \quad , \qquad (25)$$

where the unit vectors $\hat{e}_1$ and $\hat{e}_2$ are mutually orthogonal and lie in the plane normal to $\vec{r}_{ev}$. Since the relevant portion of the probes' descent through Venus' atmosphere occurs on a time scale short compared to a day, we ignore here the time dependences of $\vec{b}_{ij}$ and $\vec{r}_{ev}$.* The vectors $\hat{e}_i$ $(i=1,2)$ can be defined, for example, by

$$\hat{e}_{p1} \equiv \frac{\hat{r}_{ev} \times (\vec{\rho}_p \times \hat{r}_{ev})}{|\hat{r}_{ev} \times (\vec{\rho}_p \times \hat{r}_{ev})|} \quad , \qquad (26)$$

$$\hat{e}_{p2} \equiv \frac{\hat{r}_{ev} \times \vec{\rho}_p}{|\hat{r}_{ev} \times \rho_p|} \quad , \qquad (27)$$

where $\hat{e}_{p1}$ is parallel to the projection of $\vec{\rho}_p$ and $\hat{e}_{p2}$ is

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*These and other mathematical approximations would, of course, not be made in a realistic model to be used in an actual analysis of data.

normal to this projection. We also ignore the slight change in direction of $\vec{\rho}_p$ during final descent insofar as this change affects $\hat{e}_{pi}$. Both components of $\dot{\vec{\rho}}_{qp}^{\perp}$ are determined since we assume that the projections of the various baseline vectors $\vec{b}_{ij}$ span the plane normal to $\vec{r}_{ev}$.

How may we estimate wind speeds from this measured vector function $\dot{\vec{\rho}}_{pq}^{\perp}$? First, we assume that the horizontal velocity of each probe is equal to that of the local wind (see **Section IV**). Second, we decompose the velocity of each probe into its vertical and horizontal parts and project each onto the plane normal to $\vec{r}_{ev}$ to determine their effects on the measured vector function. Thus we set

$$\dot{\vec{\rho}}_p(t) = \dot{\vec{\rho}}_p^{\,V} + \dot{\vec{\rho}}_p^{\,H} \quad , \tag{28}$$

where

$$\dot{\vec{\rho}}_p^{\,V} \equiv (\dot{\vec{\rho}}_p \cdot \hat{\rho}_p)\hat{\rho}_p \quad , \tag{29}$$

$$\dot{\vec{\rho}}_p^{\,H} \equiv \hat{\rho}_p \times (\dot{\vec{\rho}}_p(t) \times \hat{\rho}_p) \quad , \tag{30}$$

and where we again ignore the variation in $\vec{\rho}_p$ during descent in its effect on the unit vector $\hat{\rho}_p$. In terms of these definitions and similar ones for the qth probe, we have:

$$\begin{aligned}\dot{\vec{\rho}}_{qp}^{\perp} \equiv \dot{\vec{\rho}}_p^{\perp} - \dot{\vec{\rho}}_q^{\perp} = {} & [(\dot{\vec{\rho}}_p^{\,H} + \dot{\vec{\rho}}_p^{\,V}) \cdot \hat{e}_{p1}]\,\hat{e}_{p1} + (\dot{\vec{\rho}}_p^{\,H} \cdot \hat{e}_{p2})\hat{e}_{p2} \\ & - [(\dot{\vec{\rho}}_q^{\,H} + \dot{\vec{\rho}}_q^{\,V}) \cdot \hat{e}_{q1}]\,\hat{e}_{q1} - (\dot{\vec{\rho}}_q^{\,H} \cdot \hat{e}_{q2})\,\hat{e}_{q2} .\end{aligned} \tag{31}$$

From this general expression, we can examine some special cases:

(1) One of the objects being tracked has a transponder and is not passing through the lower atmosphere. Since the trajectory for this object, say q, can be reconstructed from the Doppler data, the coefficient of $\hat{e}_{p2}$ can be isolated and will yield directly the projection of $\vec{\rho}_p^{\,H}$.

(2) Both objects being tracked are passing through the lower atmosphere, but the unit vector $\hat{\rho}_p$ and the velocity component parallel to $\vec{r}_{ev}$ are known for each probe from transponder data (or, equivalently--if it were possible, from sufficiently accurate *a priori* knowledge of the transmitter frequency for each probe). In this instance, the differential VLBI data can be used to yield the time dependence of the vector difference between the projections of the horizontal velocity components of the probes onto the plane normal to $\vec{r}_{ev}$. This function can be compared with the corresponding estimate obtained from the trajectory reconstruction.

(3) No data other than the differential VLBI data are available. Here, there are a number of subcases

that should be mentioned. First, assume $\vec{\rho}_{p2}$, $\vec{\rho}_{q}$, and $\vec{r}_{ev}$ are coplanar. We would then have $\hat{e}_{p1} = \pm\hat{e}_{q1}$ and $\hat{e}_{p2} = \pm\hat{e}_{q2}$. The combined coefficient of $\hat{e}_{p2}$ and $\hat{e}_{q2}$ in Eq. (31) would therefore yield directly the projection of the horizontal velocity difference. One can then apportion horizontal velocities between the probes in a variety of ways consistent with the measured function and with "plausibility." If $\hat{\rho}_p$, $\hat{\rho}_q$, and $\vec{r}_{ev}$ are not coplanar, the differences of the projected horizontal velocity components do not separate. Several alternatives then exist: (i) admit defeat; (ii) arrange to have one of the probes enter at the subearth point so that $\vec{\rho}_r^{\,V}$ would have no component in the plane normal to $\vec{r}_{ev}$, thus allowing the coefficient of $\hat{e}_{q2}$ to depend only on the projections of horizontal velocity components; or (iii) use all other available data to estimate $\vec{\rho}_p^{\,V}$ and $\vec{\rho}_q^{\,V}$ so that the observed function $\vec{\rho}_{qp}^{\,\perp}$ can be used to delimit the differences in the projected horizontal velocities.

(4) Null results are obtained. Suppose we get a null value for the difference in projected horizontal velocities. What other possibilities, aside from the absence of winds, would be consistent with such a result? Unless the $\vec{\rho}_p$'s are normal to $\vec{r}_{ev}$--a very unlikely event--the only other possibilities are either a cancellation of the projections from the two probes or an alignment of the projections of $\vec{\rho}^H$ and $\vec{\rho}^V$ for each probe and a consequent apparent absence of $\vec{\rho}^H$. The cancellation might come about, for example, if the winds were east-west at a constant speed, independent of height, and if the probes entered symmetrically about the meridian of the subearth point.

In summary, we have developed a mathematical model to show that in most circumstances the differential VLBI measurements will yield information on the wind speeds in Venus' lower atmosphere. But the crucial question concerns whether or not such information is useful. That question is addressed in the following section.

IV. Error Analysis

For a proper assessment of this application of differential VLBI, we must investigate a large number of possible sources of error. It has not been possible in the limited time available to carry out as complete an investigation as is required. Thus, we shall simply list many of the questions which need answering, followed in turn by the status of our analysis of each:

1. What is the basic resolution capability of differential VLBI with respect to the entry probes?
2. What are the limitations imposed by:
   - i. lack of clock synchronization between the various receiving sites on earth;
   - ii. the receiver systems;
   - iii. the atmosphere of Venus;
   - iv. the atmosphere of the earth;
   - v. the ionospheres of Venus and the earth, and the interplanetary medium;
   - vi. instability of the transmitter frequency;
   - vii. uncertainty in the geometry of entry for the probes or in the trajectory of the bus if the latter is used as a reference?

3. What are the optimum configurations of the probes with respect to positions and times of entry?

1. To determine the basic resolution capability, we note that the weakest signals will be from the miniprobes which will transmit about 1 w of effective radiated power when near the surface of Venus. If the bandwidth of this signal is no more than 50 Hz (probably a gross upper bound), then the flux at the earth will be no less than about 30 FU (1 FU = 10^{-26} w/m^2-Hz). For the antenna systems that might be used in the experiment--Goldstone, Madrid, Arecibo, Haystack, and Johannesburg--the fringe phase uncertainty, due solely to system noise, would be under 1° after only one or two seconds of integration (see, also, 2.ii below). Such a fringe phase error corresponds to a displacement uncertainty at Venus of about 6 m for this S-band signal with a projected baseline of 4000 km and an earth-Venus separation of 0.5 a.u. Thus average projected velocity differences could be measured over a time interval $\underline{t}$ with an uncertainty of only about 10 t^{-1} m/sec, where $\underline{t}$ is in seconds, if the system noise were the only source of uncertainty. We may compare this resolution with the time required for the entry probes to acquire the horizontal speed v_w of the wind. As a crude model, consider the probe to be spherical of radius R and average

density ρ . Then, if we neglect the density of the atmosphere relative to that of the probe, the probe's horizontal acceleration a_H will obey:

$$a_H = K\,(v_w - v_H) \quad , \qquad (32)$$

whence its velocity v_H will be given by

$$v_H = v_w\left(1 - e^{-K(t-t_0)}\right) , \qquad (33)$$

where the time constant K^{-1} is

$$K^{-1} = \frac{2R^2\rho}{9\eta} \quad , \qquad (34)$$

with η being the viscosity. Since the terminal vertical velocity v_V is given approximately by

$$v_V \simeq K^{-1} g \quad , \qquad (35)$$

we have $K^{-1} \simeq$ 5 sec for $v_V \simeq$ 50m/sec, etc.* The required VLBI integration time thus appears well matched to the time scales in which the probes reflect the local wind speeds in the lower atmosphere.

2.i. The lack of precise clock synchronization between the various receiving sites should introduce no detectable error if the data are properly taken. With the signals from each object tracked being sampled simultaneously, the clock error cancels completely upon differencing. In effect, the strong signal, say from the bus or main probe, acts as the clock for the weaker signals from the miniprobes. A large epoch offset of the station clock from one site relative to that from another only increases the set of trial times that

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* Here g is the acceleration of gravity on the surface of Venus.

need be introduced in the usual cross-correlation procedure used to search for fringes. However, even this minor problem disappears if advantage is taken of the presence of the carrier signal from each source as we explain below.

2.ii. The receiver system, if properly configured, also need introduce no detectable errors. We require here that the different local-oscillator signals, used at a given site to heterodyne the radio-frequency signals from the various objects being tracked, all be derived from the same frequency standard and, insofar as possible, from the same L.O. chain elements. The purpose of these strictures is to insure that almost all of the phase noise of the heterodyne signals are common to the receiver chains for all tracked objects. The common phase noise thus introduced will then cancel upon differencing. The residual (non common) phase noise can probably be reduced without much difficulty to the order of 1°.

In connection with the receiver system, we also note that the presence of a carrier signal--lacking in the usual celestial sources involved in VLBI experiments--allows the tape recording of the heterodyned signals and subsequent cross correlation to be eliminated. If the carrier signal from each probe is sufficiently stable, it can be tracked with a suitable phase-locked loop (of third order, if necessary, to follow drifts in transmitter frequency) and only the usual counted-Doppler values need be recorded. These samples can be incorporated directly into the double-difference observable defined in Section III. We must still insure that the samples for each tracked object are obtained simultaneously, or very nearly so, to insure that the clock synchronization errors cancel.

2.iii. The atmosphere of Venus can be expected to introduce sizable phase variations in the signals received at a given site from a given tracked object. The one-way electrical path length of the Venus atmosphere is about 300 m in the zenith direction. However, the phase variations introduced will be virtually identical in their effects on the signals received at each of the earth-based tracking stations. The geometric beams from a given entry probe to each of the tracking stations are separated by about 1 m at an altitude of 20 km. The Fresnel zone at that altitude for these S-band signals measures about 70 m across. Since the overlap is almost complete, this error source will largely vanish in the symmetric differencing process. The residual phase noise will be due to the small crescent-shaped non-overlap regions, separated by about 70 m at a 20 km altitude and by less at lower altitudes. This noise will depend on the spatial spectrum of the atmospheric inhomogeneities and on the wind speeds. No attempt has yet been made to estimate this contribution quantitatively.

2. iv. The earth's atmosphere introduces far less severe phase fluctuations since it has a zenith electrical path length of less than 3m--two orders of magnitude smaller than for Venus. The almost complete overlap of the beams entering a given antenna aperture from the various entry probes insures a high-order of cancellation of the atmospheric effects in the differencing procedure. No quantitative estimate has yet been made of the residual noise, although relevant noise statistics are available. In summary, the Venus atmospheric effects tend to cancel because of the differencing of the signals received at the different receiving sites whereas the corresponding effects of the earth's atmosphere tend to cancel because of the differencing of the signals from the various probes. The beauty of the symmetric double-difference technique is thus apparent.

2.v. The effect of the charged particles along the propagation paths--equivalent to a change in electrical path length of less than 15 m--will also tend to cancel in the double difference. But here there are several important differences from the atmosphere case: (a) The path separations midway between earth and Venus are about 2000 km, compared to a Fresnel zone size of about 100 km; (b) The ionospheres have peak densities at altitudes of hundreds of kilometers; and (c) The lack of exact equality among the transmitter frequencies will prevent complete cancellation of plasma effects due to dispersion. To insure that the frequency differences Δf cause corresponding variations in phase path of no more than 1°, it is necessary that $\Delta f \lesssim 20\,kHz$. If the charged-particle contributions can be modelled from other data to within 40%, then this restriction can be relaxed to $\Delta f \lesssim 50\,kHz$. The lack of cancellation due to non-overlap of the various paths again will depend on the spatial and temporal spectra of the inhomogeneities. And again no attempt has yet been made to estimate quantitatively this source of residual phase error.

It may, in fact, be possible to solve for the above propagation medium effects if all probes can be tracked simultaneously from more than three earth-based antenna sites. The multiplicity of paths provides redundancy which may be used in a suitable filtering scheme to eliminate all medium effects. (We assume that the differences in transmitter frequencies introduce negligible dispersion.) The analysis of this multi-probed many-sited situation has been started, but not completed.

2.vi. Variations in the frequencies of the transmitters make difficult their calibration by means of the one-way Doppler values. Errors in this calibration will tend to introduce asymmetries into the double-difference observable with the consequence, for example, that the propagation medium effects will not cancel as completely. An *a priori* knowledge of these frequencies, accurate to 1 part in 10^8, would certainly be sufficient to eliminate this source of error. Whether or not a knowledge of them to 1 part in 10^6--a more realistic figure--will be sufficient is uncertain. A detailed analysis of this aspect is in progress but has not been completed. With turn-around transponders, the problem all but disappears.

2.vii. Uncertainties in the geometrical configuration of the entry probe vectors $\vec{\rho}_r$ (see Section III) will affect the interpretation of the data in terms of wind speeds. Similarly, uncertainties in the velocity vector of the bus, if it is used as a reference, will introduce interpretation difficulties. Although no quantitative estimates have been made, the trajectory reconstruction for the bus should be sufficiently accurate with Doppler errors at the 1 mm/sec level or below. Hopefully, the medium effects and the unknown harmonics of Venus' gravitational field won't vitiate this conclusion. With the bus providing a reference, the small uncertainties in the entry probe geometry will be of little consequence; such will not be the case if only the several miniprobes are tracked simultaneously. But then other problems loom larger, as mentioned in Section III.

3. It would be best to have the bus tracked simultaneously with each entry probe (no entry occultations allowed during this period!) and to have the trajectory of the bus passing far enough from Venus to minimize the effects of the higher harmonics of the gravity field. Arrayed against this requirement will be the reduction in cancellation of propagation medium effects that accompanies an increase in angular separation of the targets. If the bus is unavailable, then wind speeds seem to be easiest to isolate (see Section III) if one of the simultaneously tracked entry probes is directed towards the subearth point on Venus. Again, the quantitative advantages have not been analyzed.

V. Conclusions

We conclude that wind speeds in the lower atmosphere of Venus can be detected via differential VLBI observations of the entry probes. The uncertainty in the wind speed determination can probably be kept below 100 t^{-1} m/sec, where $t > 1$ is the time resolution in seconds, provided that:

(1) the residual effect of the propagation medium on the symmetric double-difference observable can be be kept below about 10° of phase at S-band; and

(2) the transponded signals from the bus, on an exo-atmospheric trajectory, are available as a reference.

Condition (1), which is crucial, is unfortunately not buttressed by a prima facie case. The loopholes left, discussed in Section IV, are related to the effects of the non-overlap regions of the propagation paths and the instabilities of the transmitters. (We assume, in addition, that the differences in transmitter frequencies are no more than about 50 kHz .) If the signals from the bus were not available as a reference, the main probe with its transponder could serve the same function with a loss in accuracy that would probably not be too severe but that hasn't been estimated quantitatively. If only the miniprobes--without transponders--can be tracked simultaneously, the situation looks grim because of the difficulty in separating the contributions of the vertical and horizontal velocity components to the observed projections on the plane normal to the earth-Venus line. Unless the vertical velocity components can be modelled accurately, the only apparent solution in this circumstance is to have one of the miniprobes directed towards the subearth point.

Of course, if a transponder were available on each probe, all of these problems would fade away. The reconstruction of the horizontal probe velocity from the projection of the total velocity vector along the earth-Venus line should be reasonably accurate even after allowance for uncertainties in the entrance geometry, the terminal vertical velocity, and the (two-way) effects of Venus' atmosphere on the observed Doppler shift.

The main conclusion to be drawn on the potential of differential VLBI, _per se_, for the determination of wind speeds is that, despite this mass (mess?) of verbiage, much work remains to be done to assure a proper assessment.

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2. I.I. Shapiro, C.C. Counselman, and H.F. Hinteregger, "Lunar Rover Tracking Via VLBI", Report prepared for the Manned Space Flight Net, Goddard Space Flight Center, 1971.
3. C.C. Counselman, H.F. Hinteregger, and I.I. Shapiro, "Astronomical Applications of Differential Interferometry", to be submitted to Science.

8. Report on the factors affecting data rate.
(Generated 3-7-72)

RESPONSE: (3-24-72 by T. Grant)

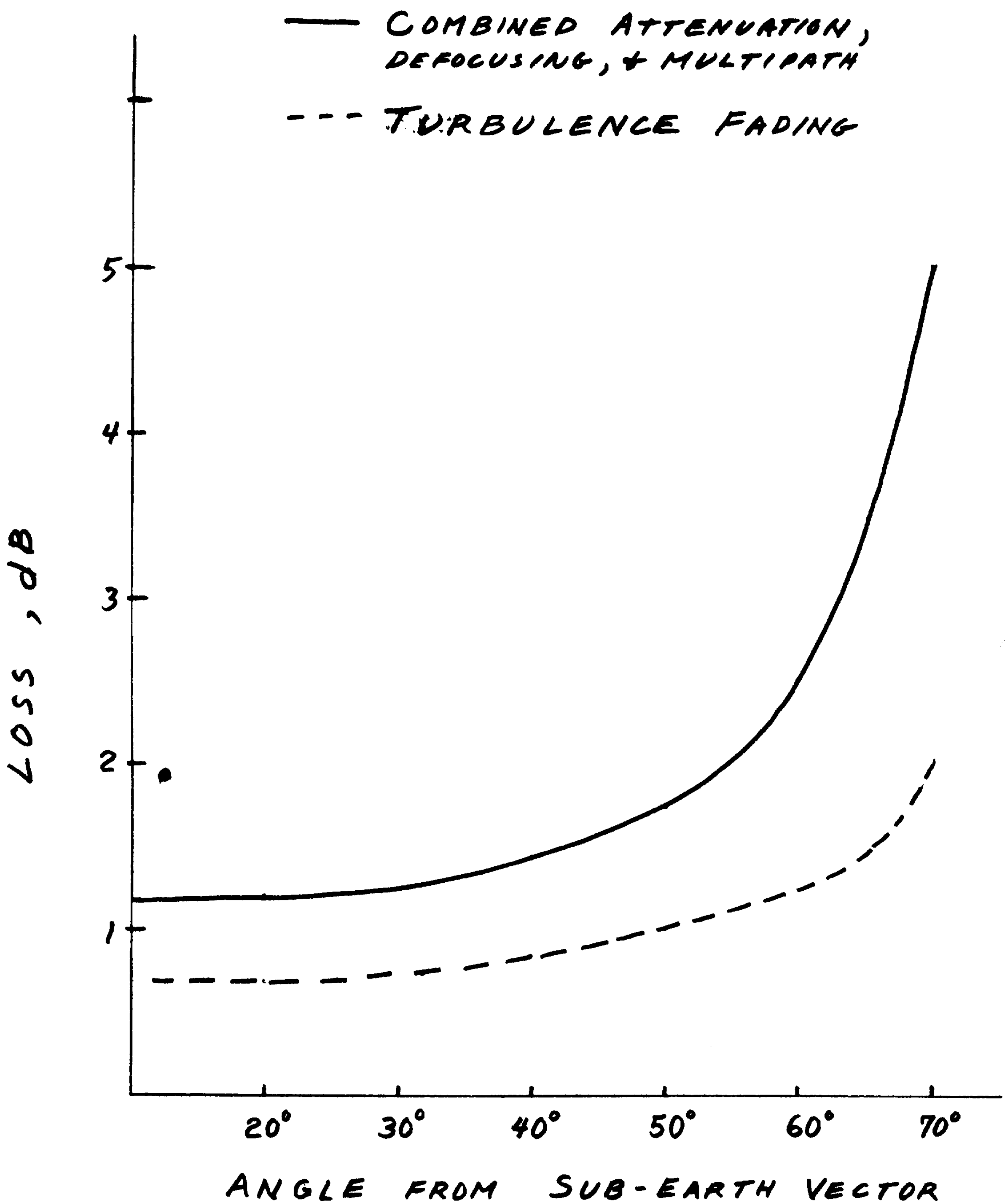
Distributed a report entitled "Probe Telemetry Factors Affecting Data Rate"

PROBE TELEMETRY

FACTORS AFFECTING DATA RATE

- R. F. POWER
- RANGE
- ANTENNA GAINS
- RECEIVER NOISE
- MODULATION AND CODING EFFICIENCY
- ATMOSPHERIC PROPAGATION LOSSES
    - a. ATTENUATION (CO_2 + H_2O)
    - b. REFRACTIVE DEFOCUSING
    - c. MULTIPATH INTERFERENCE
    - d. TURBULENCE CAUSED PHASE JITTER & FADING

ESTIMATED ATMOSPHERIC LOSSES



PROBE TELEMETRY

'76 - '77 MISSION

DATA RATES AND ATMOSPHERIC LOSS MARGIN

- LARGE PROBE - 80 BPS
  - PSK - PM MODULATION (DSN COMPATIBLE)
  - CONVOLUTIONAL CODING (RATE 1/2)
  - 10 WATT TRANSMITTER
  - 5 dB ANTENNA GAIN (AT 50°)
  - 12 Hz CARRIER TRACKING NOISE BANDWIDTH

  4.7 dB MARGIN
    - 1.8 dB BUDGET FOR ATTENUATION, DEFOCUSING, MULTIPATH
    - 2.9 dB MARGIN FOR FADING, JITTER

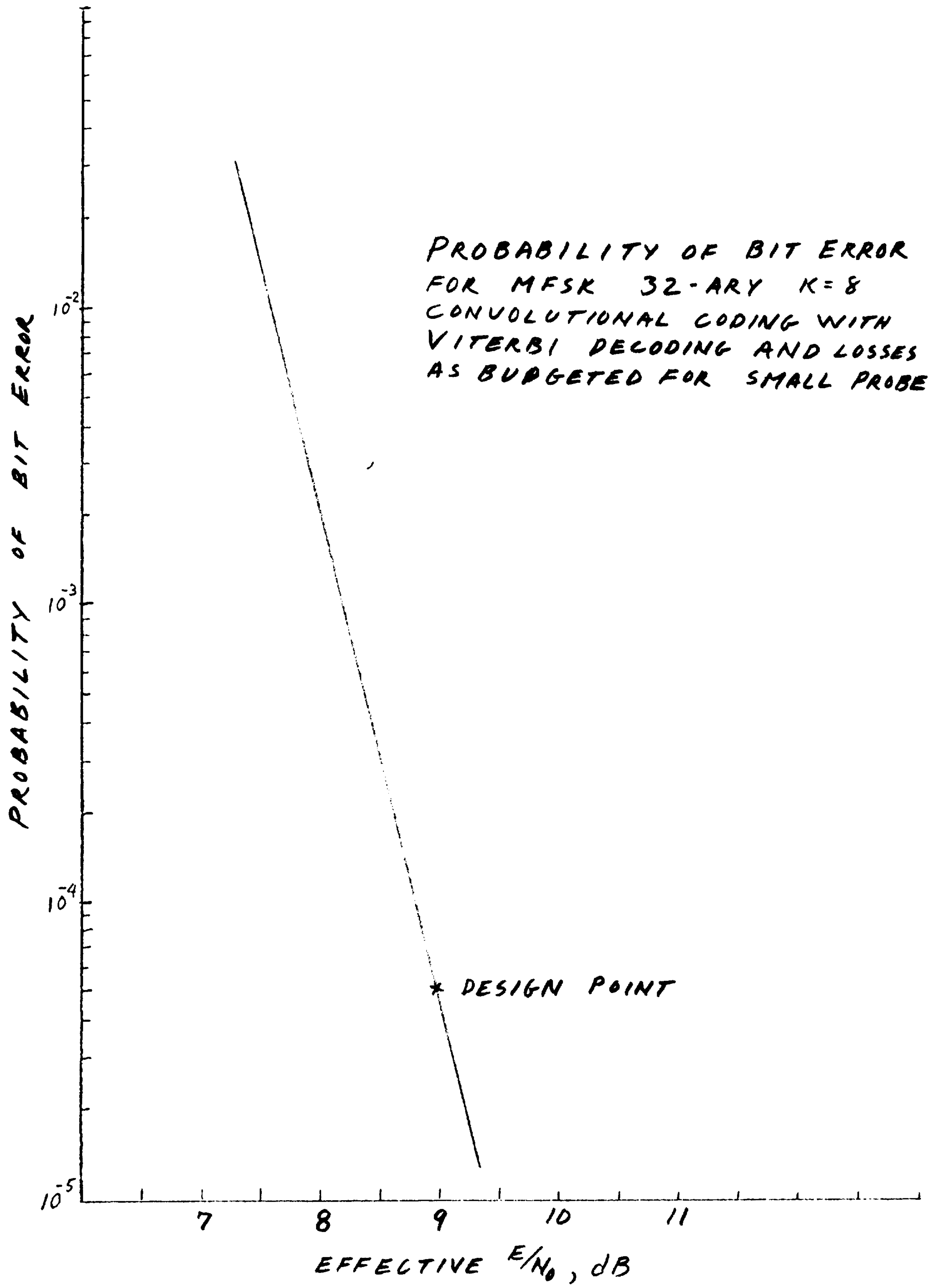
- SMALL PROBES - 4 BPS
  - MFSK MODULATION (32 - ARY)
  - CONVOLUTIONAL CODING (K = 8)
  - 2 WATT TRANSMITTER
  - 4.5 dB ANTENNA GAIN (AT 70°)
  - 3 dB BUDGET FOR RECEIVER/RECORDER LOSSES

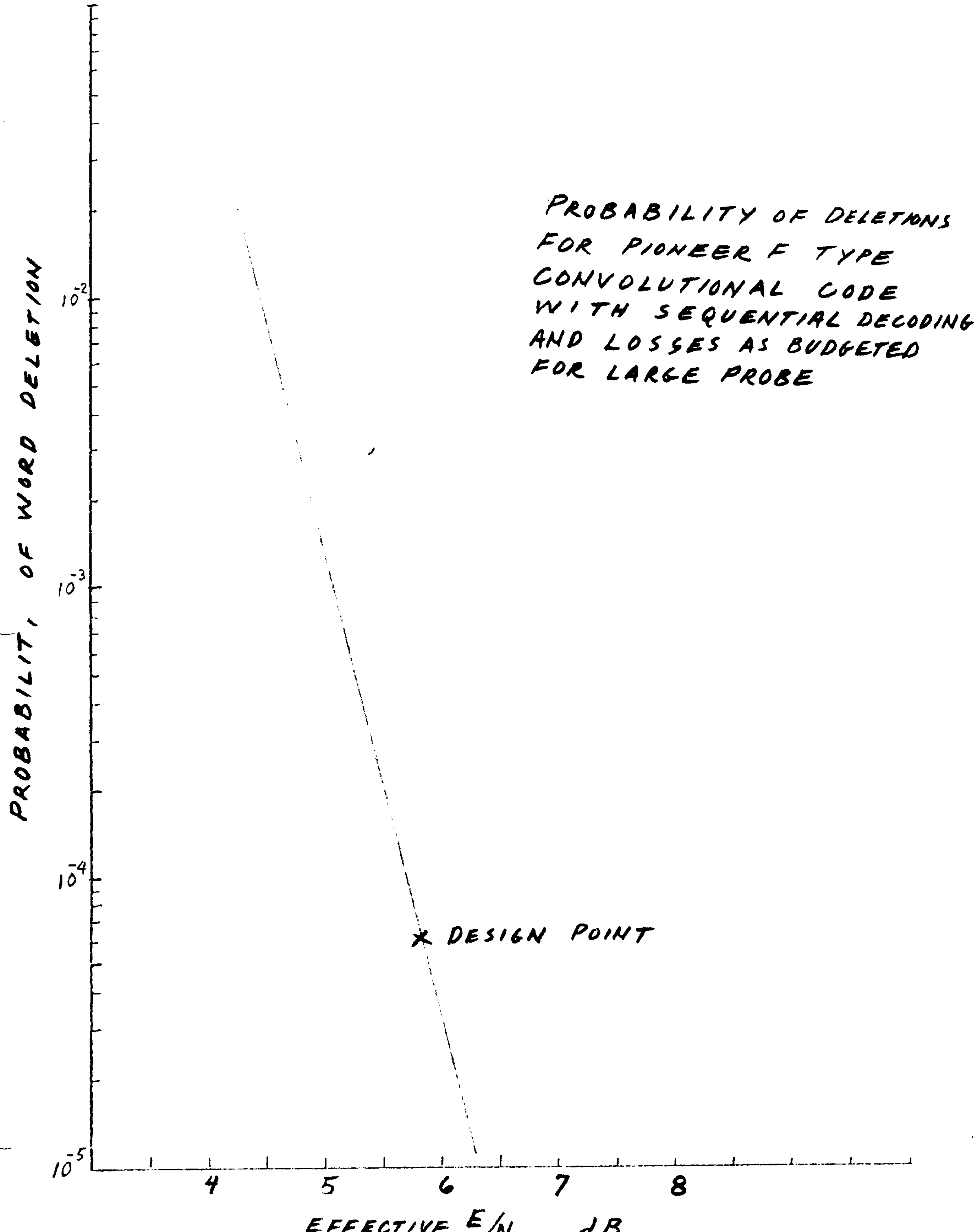
  8.4 dB MARGIN
    - 5 dB BUDGET FOR ATTENUATION, DEFOCUSING, MULTIPATH
    - 3.4 dB MARGIN FOR FADING, JITTER

  (2 BPS ⟶ 10.4 dB MARGIN)

- SMALL PROBES - 2 BPS
  - PSK - PM MODULATION (DSN COMPATIBLE)
  - CONVOLUTIONAL CODING (RATE 1/2)
  - 4 WATT TRANSMITTER
  - 4.5 dB ANTENNA GAIN (AT 70°)
  - 8 dB BUDGET FOR RECEIVER DEGRADATION (12 Hz CARRIER BANDWIDTH)

  8.0 dB MARGIN
    - 5 dB BUDGET FOR ATTENUATION, DEFOCUSING, MULTIPATH
    - 3 dB MARGIN FOR FADING, JITTER


PROBABILITY OF BIT ERROR FOR MFSK 32-ARY K=8 CONVOLUTIONAL CODING WITH VITERBI DECODING AND LOSSES AS BUDGETED FOR SMALL PROBE
PROBABILITY OF BIT ERROR
EFFECTIVE E/N0, dB
10^-2
10^-3
10^-4
10^-5
7
8
9
10
11
DESIGN POINT


PROBABILITY OF DELETIONS FOR PIONEER F TYPE CONVOLUTIONAL CODE WITH SEQUENTIAL DECODING AND LOSSES AS BUDGETED FOR LARGE PROBE
PROBABILITY, OF WORD DELETION
10^{-2}
10^{-3}
10^{-4}
10^{-5}
DESIGN POINT
4
5
6
7
8
EFFECTIVE E/N_0, dB

SMALL PROBE

TRANSPONDER TRACKING CONSIDERATIONS

- SINGLE UP-LINK/MULTIPLE DOWN-LINKS
- ACQUISITION AND REACQUISITION REQUIREMENT
- TOTAL ADDED WEIGHT IMPACT OF RECEIVER/DIPLEXER
  - RECEIVER/DIPLEXER 1.5 lbs.
  - POWER 0.5 lbs.
  - HEAT ABSORPTION 0.3 lbs.
  - STRUCTURE/SHIELD/INSULATION 1.4 lbs.

  3.71 lbs. (TOTAL)
- RISK TO TELEMETRY
- STABLE OSCILLATOR ALTERNATIVE

9. The Pioneer Venus Project is to perform a feasibility study to determine coherent vs. non-coherent tracking coverage tradeoffs for the small probes.
(Generated 3-29-72)

RESPONSE: (4-24-72 by T. Grant)

It is not clear from the action item statement wether it refers to study of coherent vs. non-coherent telemetry or one-way vs. two-way tracking from the small probes. However, studies have been initiated relative to both questions. These studies require some complex analysis and computer simulation work and will not result in accurate tradeoff information for 6 months or more.

Central to both questions is the requirement to derive a realistic, quantitative model of the effect of turbulence on the telemetry signal. Several approaches have been taken to that problem:

A study to estimate the spectral shape of the phase and amplitude noise on the signal due to turbulence is being initiated by Richard Woo at JPL. Support has been requested of Dr. Goldstein at JPL to estimate a bound on turbulence induced spectral line spread based on his radar mapping of Venus this June. Further information on the characteristics of Venera 7 data is being gathered. In addition, a study is being negotiated with Dr. Eshleman at Stanford to look at the overall characteristics of Venus atmospheric losses and estimate the effects of high zenith angles on the telemetry signal.

With regard to the study of coherent vs. non-coherent telemetry, a simulation study is being initiated by James Springett, at JPL. This study will derive performance measurements of coherent and non-coherent coded modulation as a function of perturbation parameters representing models of the turbulence effect.

With regard to the feasibility of one-way vs. two-way doppler tracking, both a transponder and a very stable oscillator (for one-way doppler) is being considered. Enough development has already been done on the transponder to establish its constraints. On the other hand, a stable oscillator design is currently being studied by the Applied Physics Laboratory, under our direction.

RESPONSE: (6-5-72 by T. Grant)

The following is an up-to-date summary of considerations of one-way vs. two-way tracking for the small probes:

9. (Continued)

1. Requirements:

a. Support of differential VLBI.

A one-way link will support a differential VLBI type of experiment; the accuracy and stability of a carefully designed onboard oscillator should be adequate. The oscillator's inherent accuracy will be on the order of 10^{-6}, but a total drift in frequency during the descent should be less than 10^{-8} with proper design.

b. Measure Range Rate.

The differential VLBI technique gives two relative velocity components in a plane perpendicular to the range. Any information about the 3rd velocity component along the range vector must be derived independently of this technique. The third component can be measured directly via one-way or two-way doppler or estimated from estimates of the probe's descent velocity and the differential VLBI. The errors in direct measurement of the third component of velocity via one-way doppler are as follows: The short term oscillator resolution error (30-120 sec. average) is estimated to be between 0.3 and 0.06 meters/sec. rms. The oscillator drift error for one hour is estimated at 3 meters/sec peak. The absolute accuracy is dependent on the ability to calibrate the oscillator frequency either before entry or after impact, and is estimated to represent an error of less than 0.3 meters per second. The error for two-way doppler due to short term resolution is less than 0.01 meters/sec. Two-way doppler is essentially drift free. Errors due to atmospheric effects on propagation have not been analyzed quantitatively as yet.

c. Telemetry.

For telemetry reception, only a one-way link is required and a two-way link would detract from the telemetry capability. For that reason no proposer for the System Design Study has considered a two-way link for the small probes in their baseline design.

2. Problems in Implementing a Two-Way Link:

a. Weight.

Further information about available diplexer weights indicates that its weight was underestimated. A more realistic weight for the diplexer is 2 lbs. This would make the total additional weight for a transponder 3 lbs. and the total impact on the small probe weight 6.7 lbs. Further consideration of diplexer weight will be included in the System Design Studies.

9. (Continued)

b. Size.

The size of the receiver and diplexer required to provide two-way doppler could be as important as their weight. The volume of a receiver/diplexer which is already developed is 150 cu. in. with the diplexer representing most of the volume.

c. Telemetry Loss.

The loss of telemetry capacity attendent to adding the two-way doppler capability stems from multiple causes:

(1) Diplexer Loss - Diplexer insertion loss will attenuate the transmitter power from 0.5 to 1 dB.

(2) Additional Spectral Spreading - It appears that probe motion as well as atmospheric turbulence will spread the carrier spectrum. This will result in a modulation loss in the telemetry which will be twice as bad for two-way tracking as for one-way. The magnitude of this loss is being analyzed.

(3) Telemetry Risk and Complexity - The receiver function is in line with the telemetry carrier generation and thus adds risk to the telemetry reception. And, some bits of telemetry are sure to be lost during any receiver acquisition cycle when the telemetry carrier reference is switched from the local oscillator to the receiver. Telemetry acquisition on the ground is also complicated by the switch-over.

3. A Solution to Some of the Telemetry Losses.

A way to overcome the effects listed in c.(2) and (3) would be to maintain the local oscillator as the only telemetry carrier reference and periodically telemeter back the difference between the local oscillator and the received frequency. The circuit development would be minimal and could be added to the data handling circuitry. A 10 bit word would have the desired resolution, and if read once per 100 seconds, the loss of telemetry rate due to this added word would be 0.1 bps.

4. Studies Related to the Problems.

a. Applied Physics Laboratory.

A study with the Applied Physics Laboratory of John Hopkins University is being directed toward a design for a stable probe oscillator.

b. Venera 7 Study.

More information on spectral spreading of the signal from Venera 7 has been requested from a secret study effort.

9. (Continued)

c. Jet Propulsion Laboratory Studies.

Several efforts have been initiated at the Jet Propulsion Laboratory and are being directed by the Pioneer Venus Project. Radar measurements of Venus are being used to establish an upper bound on turbulence-induced spectral spreading. A new formulation for turbulence loss is being generated and evaluated in relation to Mariner 5 data. In addition, low bit rate telemetry performance is being evaluated in relation to doppler perturbation as expected for the small probes.

d. Stanford University Study.

A contract is about to be signed with Dr. Eshleman at Stanford University to have his group review all atmospheric effects on a propagating signal and perform analyses to determine an upper bound on the losses. They will also be considering what propagation effects might be better defined through more detailed study.

e. System Design Studies .

The System Design Studies will include tradeoff studies on one-way versus two-way probe links and will include consideration of probe motions, oscillator stability and atmospheric propagation effects in the communication link designs.

10. It was recommended that Leovy, Lewis and Donahue be contacted as to their interests in participating at a future meeting as consultants.
(Generated 3-7-72)

RESPONSE: (6-5-72)

Dr. Lewis attended June 5 and 6, 1972, SSG meetings. He gave a presentation on his latest thoughts on the composition of the Venus Atmosphere.

Drs. Deovy and Donahue were not invited, since it was felt that they would offer duplication of the areas of expertise that presently exist on the SSG.

A summary of Dr. Lewis's thoughts is attached.

Origin and Chemistry of the Venus Atmosphere

J. S. Lewis

The general decrease of densities of solid solar system bodies with increasing heliocentric distance suggests a dependence of accretion temperature on distance, with bodies close to the Sun formed at rather high temperatures. The temperature of formation influences two observable properties of the planets; the bulk density and the degree of retention of volatiles. Calculations on the chemistry of solar material over wide ranges of temperature and pressure give detailed predictions of the bulk condensate density and of water and sulfur content which can be directly compared to observation.(1) The volatile content of the Earth is compatible with either an equilibrium origin at ~600°K, or with origin at a higher temperature with addition of ~1% by mass of volatile-rich material such as type I carbonaceous chondrites.

A model for the bulk composition and volatile content of Venus based on the equilibrium model suggests essentially zero sulfur content and zero water content, with a relatively FeO-free mantle and a solid Fe-Ni core. The observed H_2O content of the Venus atmosphere accounts for $\lesssim 10^{-9}$ of the mass of Venus, while no gaseous sulfur compounds (COS, SO_2, H_2S, etc.) have ever been detected by Earth-based spectroscopic observations. It is not clear whether this amount of water (10^4 times less than on Earth) requires a special explanation, since a single large (20 km radius) comet head could supply this amount.

Any chemical equilibrium approach to explaining the observed composition of the atmosphere in terms of chemical reactions between atmospheric gases and surface minerals shows that sulfur-bearing surface rocks would always give rise to observable amounts of sulfur gases in the lower atmosphere.(2) The observational failure to detect these gases by IR spectroscopy can be interpreted in at least three ways:

(1) Venus contains no sulfur.

(2) Venus has differentiated in such a way as to "bury" all the sulfur, or

(3) Sulfur is present in the lower atmosphere but precipitates as cloud-forming compounds below spectroscopically accessible levels.

Any in situ mass spectrometric analysis must be directed at answering three questions. First, the composition of the chemically reactive portion of the atmosphere (which is in chemical equilibrium with the surface of the planet) must be determined. Second, the abundances of gases containing elements which may form clouds must be measured deep in the atmosphere ($T = 650 \pm 100°K$), below the bases of most plausible cloud layers. The deepest possible penetration into the lower atmosphere is desirable ($T \geq 700°K$). Third, chemically-inert gases diagnostic of the amount of primordial volatile material retained by Venus should be analyzed in isolation in a chemically cleaned sample.

The most important chemically reactive gases to be measured are CO_2, H_2O, CO, HCl, HBr, HI, HF, COS, H_2S, SO_2, and compounds of As, Sb, and Hg. Among the "inert" gases, N_2, ^{40}Ar, ^{4}He, and primoridal gases such as ^{3}He, ^{20}Ne, ^{22}Ne, ^{36}Ar, ^{38}Ar, Kr and Xe, would all be useful. Among these the fundamental importance of sulfur, nitrogen, and light rare gases commend tham especially to our attention.

If it is assumed that several mass spectrometer analyses at widely separated altitudes, and detailed nephelometer data, will be available, then there is no significant advantage to attempting direct analyses of cloud particles. Pressure and temperature profiles combined with available thermo-chemical data would permit a straight-forward calculation of the altitudes at which various components of the lower atmosphere would saturate.

The dynamic range required of the mass spectrometer is dictated by the expected abundances of Br, I, S, Hg, As, and Sb in the lower atmosphere. Cloud-forming condensates with abundances less than 10^{-6} of CO_2 will be unimportant, while a terrestrial analogy suggests upper limits of $\sim 10^{-2}$, 10^{-3}, 10^{-4}, 10^{-3}, 10^{-3} and 10^{-4} for the respective mole fractions of the elements. A dynamic range better than $10^{4}:1$ is required, and $10^{5}:1$ is a reasonable minimum target.

(1) J. S. Lewis, Earth Planet. Sci. Lett., in press (1972).
(2) J. S. Lewis, Earth Planet. Sci. Lett., 10, 73-80 (1970).

11. The Pioneer Venus Project is to provide a model atmosphere for use by the SSG. This model should include the study being conducted by Aerospace Engineering Associates. (Generated 3-29-72)

RESPONSE: (3-29-72)

Following a brief discussion on ml atmospheres, Dr. Goody requested the Project Office provide a "strawman" for the SSG to critique. Dr. Colin indicated that the GSFC model 3609 was the projects' choice for the RFP. However, the project was awaiting the release of a new study on the Venus atmosphere being prepared by Aerospace Engineering Associates in Cambridge, Massachussetts. (Dr. Mc Elroy is being used as a consultant). Dr. Bauer indicated that the first draft is ready for review. Dr. Goody requested an attempt be made to expedite the study's release.

RESPONSE : (4-24-72)

A draft copy of the Aerospace report, excluding the atmosphere models, has been obtained and is available for review. The Aerospace people are attempting to run the models on their computer in time for the 3rd SSG Meeting.

It was agreed that A. Seiff will critique the new model atmosphere when received.

Also distributed was a report by R. Goody entitled "Velocities and Temperatures Anticipated in the Venus Atmosphere."

RESPONSE: (6-5-72)

Mr. Seiff gave a verbal report. The Aerospace will be reviewed at GSFC on June 12, 1972, and probably be released before July 1, 1972.

It was agreed that the SSG will define the maximum pressure and temperature to which the probe must survive based on scientific rationale. The actual environmental extremes to which the probes will be tested will be defined by the Pioneer Venus Project Office.

Velocities and temperatures anticipated in the Venus atmosphere

by Richard Goody

1. Measurements.

In middle latitudes, at the entry point of Venera-7, the atmosphere is close to adiabatic with a ground temperature $\sim 750^{\circ}K$ and a pressure of about 90 atmospheres.

This close-to-adaibatic state must exist over the whole planet, from pole to equator and day to night, because the surface temperature and the temperature of the cloud tops ($\sim$ 100 mb) do not vary greatly over the planet. The problem of temperature measurement is to detect small departures from adiabaticity and small horizontal temperature variations (along constant pressure surfaces).

The most complete analysis of thermal maps is that by

R. Goody, 1965, 'The structure of the Venus cloud veil', J.G.R., 22, 5471-5481.

Equator to pole temperatures are 207 K to 185 K (the absolute calibration of the radiometer may be poor but the temperature difference should be real). We cannot be certain that the cloud tops are at a constant pressure level, however carbon dioxide line profile measurements have not given any indication to the contrary.

According to the thermal radiometric observations, the day-to-night variation is negative i.e. night hotter than day. The difference varies with viewing angle but can be as much as $6^{\circ}K$ for sub-solar to anti-solar point.

Temperatures at the surface of the planet can be measured by microwave interferometry:

A.C.E. Sinclair et al. 1970, 'Preliminary report on interferometer observations of Venus at 11.1 cm wavelength', Radio Science, 5, 347-354.

According to this paper an upper limit of 12 K can be placed on equator-to-pole variations. A significant day-to-night variation of 18.4 $\pm$ 9.2 K was reported with the maximum 30° into the night side from the terminator.

The only data existing with respect to winds is for the 4-day rotation, which now seems to be reasonably well established. Recent interferometric observations (Traub, unpublished) indicate an erratic phenomenon. Nevertheless there is a tendency towards a zonal circulation (i.e. parallel to latitude circles), at least in tropical regions, with a velocity of 100 m sec^{-1}. These observations apply to the 200 mb level and above. The rotation is retrograde and 30 times faster than the apparent motion of the sun; it is more than 60 times faster than the apparent motion of the stars.

There is no evidence that these 100 m sec^{-1} winds exist at levels other than the cloud tops.

2. Theory of the 4-day circulation.

One of the latest papers, which refers to most other theoretical works of importance, is

P.J. Gierasch, 1970, 'The four-day rotation in the stratosphere of Venus: A study of radiative driving', Icarus, 13, 25-33.

According to this paper and to those of Schubert and Malkus the circulation is a Halley circulation driven by the moving sun. Thompson views the motion as a non-linear instability, independent of the rotation of planet. In the latter case it is difficult to predict what might happen in the deep atmosphere, but in the former case the circulation will only reach down to the levels at which there is a significant diurnal temperature change.

We know from observation that there is only a small diurnal change of temperature at the cloud tops, and therefore the 4-day circulation may not penetrate at all below this level.

According to Gierasch's model (which is not universally accepted), the maximum velocity of 100 m sec^{-1} occurs at about the 50 mb level and the temperature contrast between day and night sides will be about 5° K.

3. The deep circulation: similarity arguments.

Since so little is known about the lower atmosphere it is particularly valuable to have investigations based upon similarity arguments for these are imposed constraints which must be obeyed regardless of details of the mechanism. Two are available:

G.S. Golitsyn, 1970, 'A similarity approach to the general circulation of planetary atmospheres', Icarus, 13, 1-24;

and

P. Gierasch, R. Goody and P. Stone, 1970, 'The energy balance of planetary atmospheres', GFD, 1, 1-18.

Some of the fundatmental assumptions differ between these two papers, and the results are therefore debatable. However, despite qualitative differences, they give somewhat similar numerical values for Venus.

Gierasch et al. compare the fundamental radiative time constant for the whole atmosphere (t_s) with the length of the day (t_{day}). The ratio $t_s/t_{day} \sim 10^2$ so that the maximum diurnal variation, if the solar energy is shared throughout the atmosphere, is about 2° K. This is the maximum at ground level. At other levels, assuming all the solar radiation to be deposited above the level concerned, the amplitude increases inversely as the pressure, since $t_s \propto p^{-1}$.

Mean velocities are given by

$$v \sim \frac{\theta_e}{\delta\theta} \frac{R_o}{t_s}$$

Where $\theta_e \sim 230$ K is the equilibrium temperature, $\delta\theta$ is the temperature contrast and R_o is the radius of the planet.

The temperature contrast is

$$\frac{\delta\theta}{\theta_e} \sim \left(\frac{t_o}{t_s}\right)^{2/3}$$

where

$$t_o = \frac{R_o}{\sqrt{R\theta_e}} \sim \frac{R_o}{2 \times 10^4}$$

where R is the gas constant.

If all the solar radiation penetrates to the ground

$$\delta\theta \sim 0.2^{\circ}\text{ K}$$

$$V \sim 6 \text{ m sec}^{-1}.$$

For other conditions

$$\delta\theta \propto p_o^{-2/3}, \quad V \propto p_o^{-1/3}$$

where p_o is the limit of penetration of the solar energy.

Golitsyn's study gives, for similar conditions,

$$\delta\theta \sim 1^{\circ}\text{ K}$$

$$V \sim 40 \text{ cm sec}^{-1}$$

and

$$\delta\theta \propto p_o^{-1/2}, \quad V \propto p_o^{-1/2}.$$

Gierasch et al. point to a significant difference between the atmosphere below and above the clouds. If the solar radiation is all absorbed in the clouds, and if motions distribute the heat, as theory and observation indicate, there may be an upper 'stratospheric' regime in which there are virtually no horizontal contrasts, and no horizontal drives. The question of the 4-day rotation comes in here, and has yet to be treated satisfactorily, but as far as equator-to-pole contrasts are concerned these authors estimate that a radiatively controlled, 'stratospheric' regime could start at about 200 mb pressure i.e. close to the visible cloud tops.

4. The deep circulation: heuristic models.

The relevant papers are:

R.M. Goody and A.R. Robinson, 1966, 'A discussion of the deep circulation of the atmosphere of Venus', Ap. J., 146, 339-355;

and

P.H. Stone, 1968, 'Some properties of Hadley regimes on rotating and non-rotating planets', J. Atmos. Sci., 25, 644-657.

The model of Goody and Robinson was proposed in order to understand whether the deep atmosphere might be adiabatic without any penetration of solar radiation i.e. when all the radiation is absorbed at the cloud tops. Stone's paper is an extension of this work.

Without any solar penetration only very slow velocities can be expected near to the surface, and unmeasurably small temperature contrasts. Since both treatments are two-dimensional, no distinction is made between zonal and meridional contrasts and velocities.

E. de Rivas makes the following comparison of cloud top conditions for her numerical calculations and the above two papers:

Table I
Velocities & temperature contrasts near the cloud tops for cloud-top absorption of solar radiation.

	Stone	de Rivas	Goody and Robinson
b.l. thickness (km)	1.0	1.0	1.2
horizontal velocity (m sec^{-1})	0.43	5	34
vertical velocity (cm sec^{-1})	0.1	1	0.12
temperature contrast (^{o} K)	6	18	40

5. The deep circulation: numerical models.

A fundamental problem with all of these investigations is that they can only integrate for about 100 earth days. Gierasch, Goody and Stone stressed, however, that the thermal adjustement time for the lower atmosphere is almost 10^4 earth days. It is very doubtful whether a useful result can be obtained from a time-marching technique under these circumstances.

The following two papers do not give enough detail to determine temperature contrasts in the lower part of the atmosphere.

S. Hess, 1968: 'The hydrodynamics of Mars and Venus', The atmospheres of Venus & Mars, New York, Gordon & Breach;

and

T. Sasamori, 1971: 'A numerical study of the atmospheric circulation on Venus', J. Atmos. Sci., 28, 1045-1057.

A Soviet group has used a terrestial weather prediction scheme to integrate from 90 or 160 earth days:

D.V. Chalikov et al. 1971, 'Numerical experiments of the general circulation of Venus' atmosphere'. Tellus, 23, 483-488.

They used a two-layer model, with a base at 80 atmospheres, divided at 40 atmospheres. Their upper-level results are therefore for the 20 atm. level while the lower-level is 60 atm.

Two patterns of solar absorption were considered. In one case 80% of the available radiation reaches the ground (greenhouse model). In the other case the radiation is all absorbed in the upper layer (Goody-Robinson model). The greenhouse model was investigated more extensively. Chalikov et al. conclude that the circulation is symmetric about the equator but not about the pole of rotation or the sun-planet direction, and that the highest temperatures lag significantly behind the maximum insolation.

Table II gives estimates of the maximum temperature excursions (not to be confused with average day-night temperature differences which are considerably less).

Table II
Temperature excursions ($^{\circ}$ K)

Model	Level	Diurnal	Latitudinal
Greenhouse	Surface	2.5	1.5
	60 atmos.	1.4	0.9
	20 atmos.	1.2	0.6
Goody-Robinson	Surface	1	
	60 atmos.	0.25	
	20 atmos.		

The kinetic energy per unit mass was about the same for both models, corresponding to a horizontal wind of 5.5 m sec^{-1}. Vertical winds have a maximum of a few cm sec^{-1}.

Deviations from adiabaticity in the vertical are not given explicitly, however it is possible to infer that the derivatives must be a few degrees per 100 km or a few parts per thousand of the adiabatic lapse rate.

de Rivas' study is based upon spherical co-ordinates but with time-independent solar heating with different geometries.

E.K. de Rivas, 1971, 'Circulation of the atmosphere of Venus', Ph.D. thesis, MIT.

One of her models is for a non-rotating atmosphere with an optical depth for solar radiation of 13.76 and for thermal radiation of 222.0. The vertical mixing coefficient is 10^4 cm^2 sec^{-1}. With these data the solar radiation only heats the top 1/3 of the atmosphere. In this region winds can be 30 m sec^{-1}. In the middle levels winds are 1 cm sec^{-1} or less, and at low levels they are 1 or 2 cm sec^{-1}. Horizontal temperature differences are 3° K near the top, 1° K at 25 kms and very small near to the surface. Vertical departures from adiabaticity are 0.3 to 1.5° K km^{-1} in the upper part of the atmosphere.

This model would not by itself maintain a deep adiabatic state, and therefore does not simulate the Venus atmosphere well.

A model with $K = 10^3$ cm^2 sec^{-1} gave similar results except that the interior circulation is ten times stronger i.e. about 10 cm sec^{-1}.

Finally de Rivas considers a model with solar optical depth = 2.3. This allows 6% of the solar radiation to reach the surface and hence gives rise to a substantial greenhouse effect. The high ground temperature however requires dynamical heating in addition to radiative and diffusive heating in order to maintain it.

This model has relatively large temperature contrasts even at the ground ($\sim 1.5^{\circ}$K), and the vertical stratification is almost 0.2° K km^{-1}. de Rivas does not state the value of the wind velocities near to the ground, but they must be 10 to 100 cm sec^{-1} to create the required advection effects.

6. Conclusions

(i) There are a wide variety of theories both for the four-day circulation and for the deep circulation. A few well-conceived measurements are now needed if the subject is to advance further.

(ii) The atmosphere divides naturally into two regions at about 100 mb. Above this level diurnal and other short-period effects may be large and dynamical heat transfer relatively small: the dominant winds may be zonal. Below this level the atmosphere has a very long thermal time constant and can be compared to the earth's oceans as closely as to the earth's atmosphere. The region above 100 mb is above the clouds. It can be monitored from satellites and from the ground. A device such as IRIS, carried on Mariner 9, would be ideal for investigating the this upper region. Balloons would be the best way to measure its winds. Early probes should therefore be optimized for the lower atmosphere, which we may define as pressures above 3 atmospheres.

(iii) The nature of the circulation depends critically upon penetration of solar energy. The need for simultaneous measurements of cloud scattering properties is clear, and suggests that the priority of a nephelometer on the miniprobes should be raised.

(iv) The vertical temperature gradient may depart from the adiabatic lapse rate by as much as 1%. This should be measurable with thermometers having a sensitivity of 0.1° K. Accuracy need not be high and the pressure-time relationship need not be measured directly if height-time is obtained by radio methods.

(v) Horizontal temperature gradients may be small. However, if the ground based interferometric measurements are correct, we can anticipate up to 10° K contrast at the surface. Equator-to-pole contrast may be a few $^{\circ}$ K. A relative accuracy between probes of 0.5° K is therefore desirable. The absolute accuracy of temperature measurement need not be high: 1% should be sufficient.

(vi) Further theoretical studies are needed, but these must be of a climatological nature (i.e. seeking the non-linear steady state) rather than using time marching techniques as has been done in existing studies.

(vii) Winds at pressures less than 1 atmosphere may be high, in the range 10 to 100 m sec^{-1}. It seems probable that lower atmosphere winds are well below 1 m sec^{-1}, but greater than 1 cm sec^{-1}. A precision of 10 cm sec^{-1} in horizontal wind measurements would be of great value. All theoretical treatments agree in predicting small average vertical velocities in the planetary circulation (they have little to say about turbulent eddies). It is not likely that a satisfactory measurement of the steady vertical component can be made from an entry probe.

Center for Earth & Planetary Physics
Harvard University

4/17/72

RMG/eh

12. Establish reasons for fly by of the bus (generated 3-9-72) as part of action item to report on the "geoscience" implications of magnetometer experiments from orbiter and spacecraft.

RESPONSE: (3-29-72 by C. Russell)

Distributed report entitled "Arguments for a Flyby of the Pioneer-Venus Bus."

RESPONSE: (4-24-72 by C. Russell)

Distributed report entitled "Recommendations for Bus."

RESPONSE: (6-5-72 by U. von Zahn)

Distributed report entitled "Note on the Maximum Fly-by Altitude for the Bus."

Arguments for a Flyby
of the Pioneer-Venus Bus

Major

1. Flyby provides <u>synoptic</u> horizontal swath to complement vertical profiling of the probes.

2. Flyby provides two occultations. An occultation provides the <u>only</u> measurement possible from 65 to 150 km, and it ties the data obtained from the bus and probes together.

Minor

1. Provides radio target for absolute referencing of probe positions.

2. Provides the only opportunity on this mission for measurements near local Venus noon.

3. Provides control point in interplanetary medium during Venus encounter of second launch. This is useful for particles and fields experiments (and radio?).

Additional Considerations

1) We must determine the altitude of a flyby and the altitude of data loss on an impact trajectory.

2) We must determine the amount of data returned in this region. Note for a 300 bps rate, MMC has estimated for an ion mass spectrometer*.

Altitude	Duration	Measurements
1050-440 km	3 min	40
440-270	1	17
270-200	40 sec	9
<200	∿20 sec	6

*Using 1/4 of the telemetry bit stream.

3) We must consider the importance of data in this region. Note that the neutral scale height above 150 km is about 100 km.

4) We must consider the possibility of obtaining similar data on orbiter. Drag circularization orbit must be within one scale height of impact altitude of probe. Only obvious difference is non-simultaneity with probe data.

Christopher T. Russell
March 29, 1972

TO: Bus Subcommittee

FROM: Chris Russell

SUBJECT: Recommendations for Bus

DATE: April 21, 1972

I. Introduction

The two principal questions we must answer are as follows:

a) Should the bus crash or flyby?

b) What payload achieves the maximum scientific return within the power and weight constraints and overall objectives of the mission?

These two questions are of course coupled, but I maintain only weakly so because there is only one experiment (listed as possible in the purple book) which could possibly justify crashing the bus. All other experiments would benefit from a flyby.

In this note, I list some of the arguments for a flyby again, alternative means of obtaining the data lost (?) during a flyby and questions on the payload for our consideration.

II. The Flyby

If the bus flies by Venus at as low an altitude as possible, then the bus will map out a horizontal path across the face of Venus which will complement the vertical profile obtained by the probes. This is especially valuable for those measurements which will vary slowly with altitude such as the ion mass spectrometer, the electron/ion probe, the magnetometer and the electric field/sferics detector. It is claimed that the neutral mass spectrometer will not benefit from a flyby. However, from project and contractor estimates, this would amount to only about 6 measurements. Furthermore, it is possible to achieve these data by alternative and perhaps superior means as outlined in the next section.

The second advantage is that the flyby provides two occultations. This will provide the only presently scheduled measurement possible from 65 to 150 km, and would tie bus and probe measurements together. (We note that the accelerometer and shock layer radiometer with stored data could provide measurements in this area.) The flyby also doubles the amount of data in the solar wind interaction region.

Further benefits are: the use of the flyby bus as a radio target for absolute referencing of probe positions; the only opportunity on this mission for measurements near local Venus noon; and the availability of a control point in the interplanetary medium during the second encounter. This latter measurement is of extreme value in distinguishing between various models of the Venus solar wind - ionospheric current system.

III. Alternatives to the Neutral Mass Spectrometer

The purple book bus payload lists either a neutral mass spectrometer or an ion mass spectrometer. The project's nominal payload lists both. This deviation from the recommendations of the Venus Study Panel has not been justified to my knowledge. In view of the difference in weight (10 versus 3 lbs) and power (12 versus 1 watt), it seems quite reasonable to choose the ion mass spectrometer instead of the neutral mass spectrometer.

If neutral mass spectrometer measurements are essential, these can be made in other ways. First, they could be delayed until the orbiter, on which control of periapsis altitude will be possible. Alternatively, if it is essential that neutral mass spectrometer measurements be made at high altitude, then a shock layer radiometer could be carried by the large probe. The data would be stored for transmission after blackout and the instrument could be discarded with the heat shield. The important questions to be answered if this technique is to be considered are: 1) what is the altitude range over which reliable measurements can be made and 2) what constituents can reliably be measured?

IV. Payload

1. Probable weight of scientific payload.

The purple book lists a payload of 25 lbs, the nominal project payload adds up to 26 lbs with 22 lbs in the growth payload. We should double check payload weight.

2. Solar Wind Probe and Magnetometer.

The project nominal payload includes a solar wind probe, but relegates the magnetometer to the additional payload. Can any new (or useful) science be done by solar wind probe without a magnetometer at Venus or in cruise mode? Alternatively can any new (or useful) science be done by a magnetometer without a solar wind probe at Venus or in cruise mode?

3. Electron temperature probe and ion retarding analyzer.

The purple book states ion trap or Langmuir is recommended. The project nominal payload has both measurements included. Are they both necessary? If not, which is more important? Can these measurements be performed with a single instrument with a savings in cost, weight and/or power?

4. UV Photometer.

How do these measurements complement or supplement the other measurements? Can these measurements wait until the orbiter? Do these measurements put any restraints on the orientation of the spin axis of the probe (and thus affect communications)?

5. Electric Field Detector.

The weight or project payload list is double that in purple book. The weight in project book may be for DC electric field experiment or include weight of long boom? Is a DC electric field experiment feasible? Is an AC electric field experiment feasible? Can the AC electric field antenna be mounted on the magnetometer boom? Can an AC electric field experiment on the bus serve as a sferic detector in place of a miniprobe or large probe experiment?

6. Other Experiments.

Are there any good reasons for flying

a) neutral pressure gauge,

b) UV spectrometer,

c) photoelectron spectrometer,

d) search coil magnetometer,

e) other instruments?

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June 2, 1972

v.Z/K.

Note on the Maximum Fly-by Altitude for the Bus

U. von Zahn

One reason for putting a neutral gas mass spectrometer onboard the bus is the attempt to determine the altitude of the turbopause in the Venus atmosphere. To this end altitude profiles will be measured of at least 2 or better 3 chemically and photochemically inert gases, which must all have notably different molecular weights. By comparing the density ratios obtained in the lower and upper atmosphere and assuming diffusive equilibrium above the turbopause the altitude of the turbopause can be determined with an accuracy of $\pm$ 2 km (my personal estimate).

There is not much choice in selecting these gases: only He, N_2, and Ar appear to be useful. We know however from the terrestrial thermosphere that He does not necessarily need to be in diffusive equilibrium. Therefore it is only the second best choice for the evaluation of the turbopause height.

Clearly the best suited pair of gases is N_2 and Ar. The relative argon content of the Venus atmosphere however is estimated to be considerably lower than on earth. The following numbers are quoted from Knudsen and Anderson (J.G.R. 74, 5629, 1969):

Mixing ratio in lower atmosphere

$n(Ar^{40})/n(CO_2)$	1×10^{-4}
Radius of turbopause	6180 km
$n(Ar^{40}) \simeq 10^{8}$ cm^{-3} at	6180 km
$\simeq 10^{7}$ cm^{-3} at	6190 km
$\simeq 10^{6}$ cm^{-3} at	6210 km

In terrestrial investigations the lower limit of measured argon densities lies presently somewhere between 3×10^{6} to 1×10^{7} cm^{-3} (due mainly to background problems). This indicates, that for the case of the Venus thermosphere argon measurements are probably restricted to an altitude range of about 30 km above the turbopause, that is a radius smaller than 6210 km.

Any flyby with a minimum distance larger than 6210 km will therefore in effect eliminate the possibility of determining the turbopause height.

13. Estimate of the minimum safe fly-by altitude for the bus. (Generated 3-29-72)

<u>RESPONSE</u>: (4-24-72 by R. Jackson)

Distributed report entitled "Bus Flyby Study for 1976/1977 Venus Pioneer Probe Mission."

<u>RESPONSE</u>: (6-5-72 by R. Jackson)

The flyby corridors contained in the report distributed at the April 24, SSG meeting are still the best estimates available.

Flyby corridors will be examined during the systems design study

If the SSG will define a criteria for acceptable flyby corridors, the project office will be able to evaluate the system design study results.

BUS FLYBY STUDY

FOR

1976/1977 VENUS PIONEER PROBE MISSION

BUS FLYBY STUDY

FOR

1976/1977 VENUS PIONEER PROBE MISSION

1. SUMMARY

For the 1976/1977 Probe Mission, targeting a spacecraft bus to flyby instead of impact offers a long sampling time in the lower atmosphere and an occultation by Venus.

The minimum altitude during the flyby will be determined by the expected trajectory dispersion as well as the atmosphere density model.

Venus arrival dates which permit periapsis visibility correspond to those which might be used for the second probe mission.

Periapsis and occultation will be at northerly Venus latitudes on the Sun side of the planet.

The post encounter orbit will lie near the plane of the solar equator.

2. BUS FLYBY ALTITUDES

The bus flyby corridor results from two constraints: The minimum safe altitude for a flyby, and the uncertain knowledge of the actual trajectory.

Minimum Safe Altitude

The minimum altitude during a flyby must insure that blackout does not occur.

Blackout will be virtually simultaneous with the first sensed aerodynamic deceleration, which is proportional to ρV^2. The altitude for blackout then, will depend on the entry velocity (V^2) and the atmospheric density (ρ).

The effect of entry velocity turns out to be small (less than one km change in minimum altitude for entry velocities between 4.0 and 5.0 km/sec). The effect of atmosphere density uncertainty is larger, (about 6 km change in minimum altitude from the difference between the GSFC 3609 model and the V-5 model of SP-8011).

The minimum safe altitude is about 120 km for the GSFC 3609 atmosphere model.

Trajectory Uncertainty

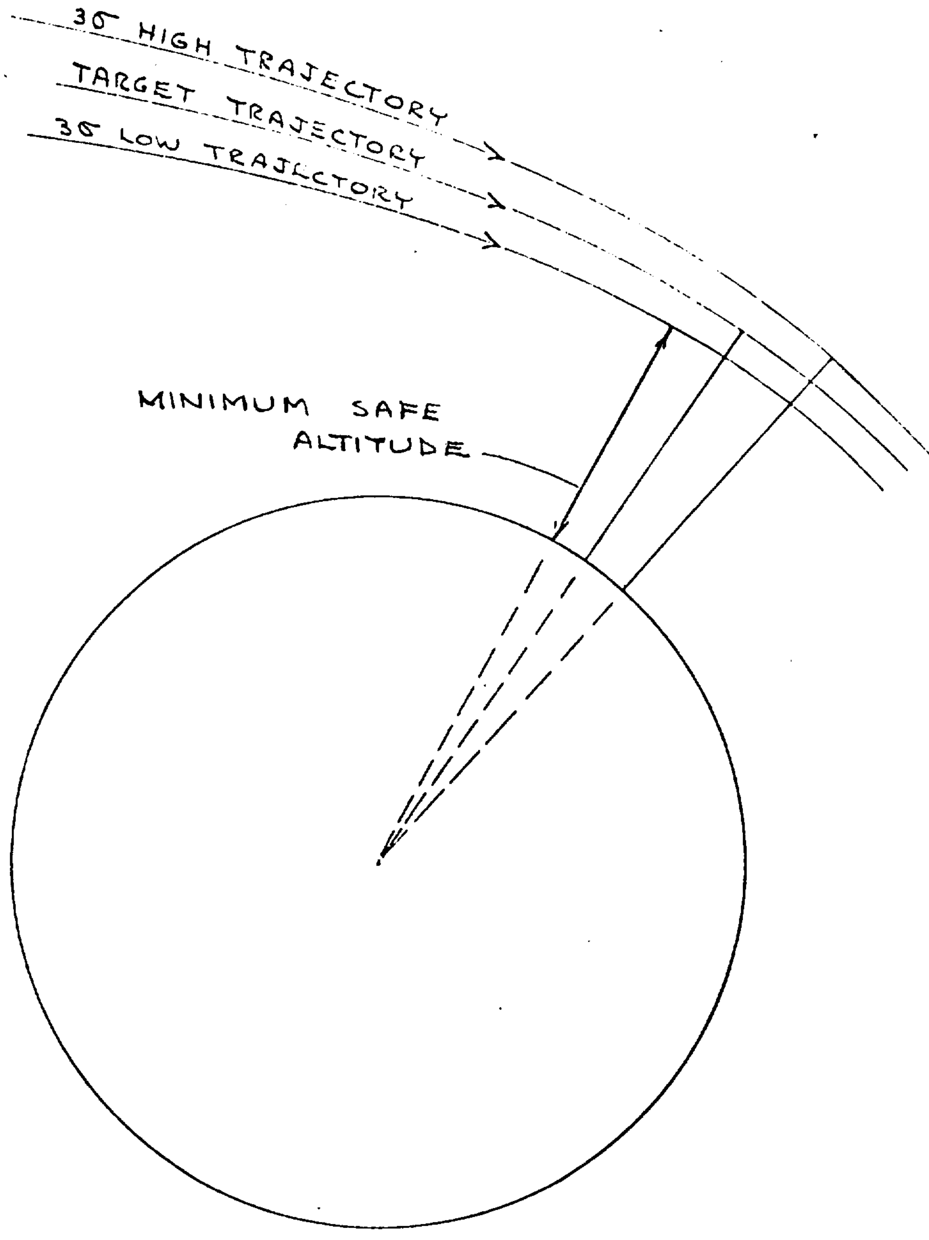
To insure a successful flyby, the bus trajectory must be targeted higher than the minimum safe altitude. The actual trajectory will lie within a corridor whose size will be determined by the expected trajectory errors.

The expected trajectory errors will depend on tracking accuracy, and bus trajectory correction accuracy, which are not well defined yet.

A reasonable estimate of the trajectory errors is between ± 100 km and ± 190 km for ± 3 Sigma probability. (99.74% probability that the actual trajectory will not be farther from the target than these limits).

The errors in closest approach altitude will be somewhat smaller because the trajectories will be "gravitationally focused."

	Trajectory Corridor		
3 Sigma Trajectory Uncertainty	Min. Altitude	Target	Max. Altitude
± 100 km	120 km	193.5 km	267 km
± 190 km	120 km	260.0 km	400 km



EFFECT OF TRAJECTORY ERRORS ON FLYBY ALTITUDE

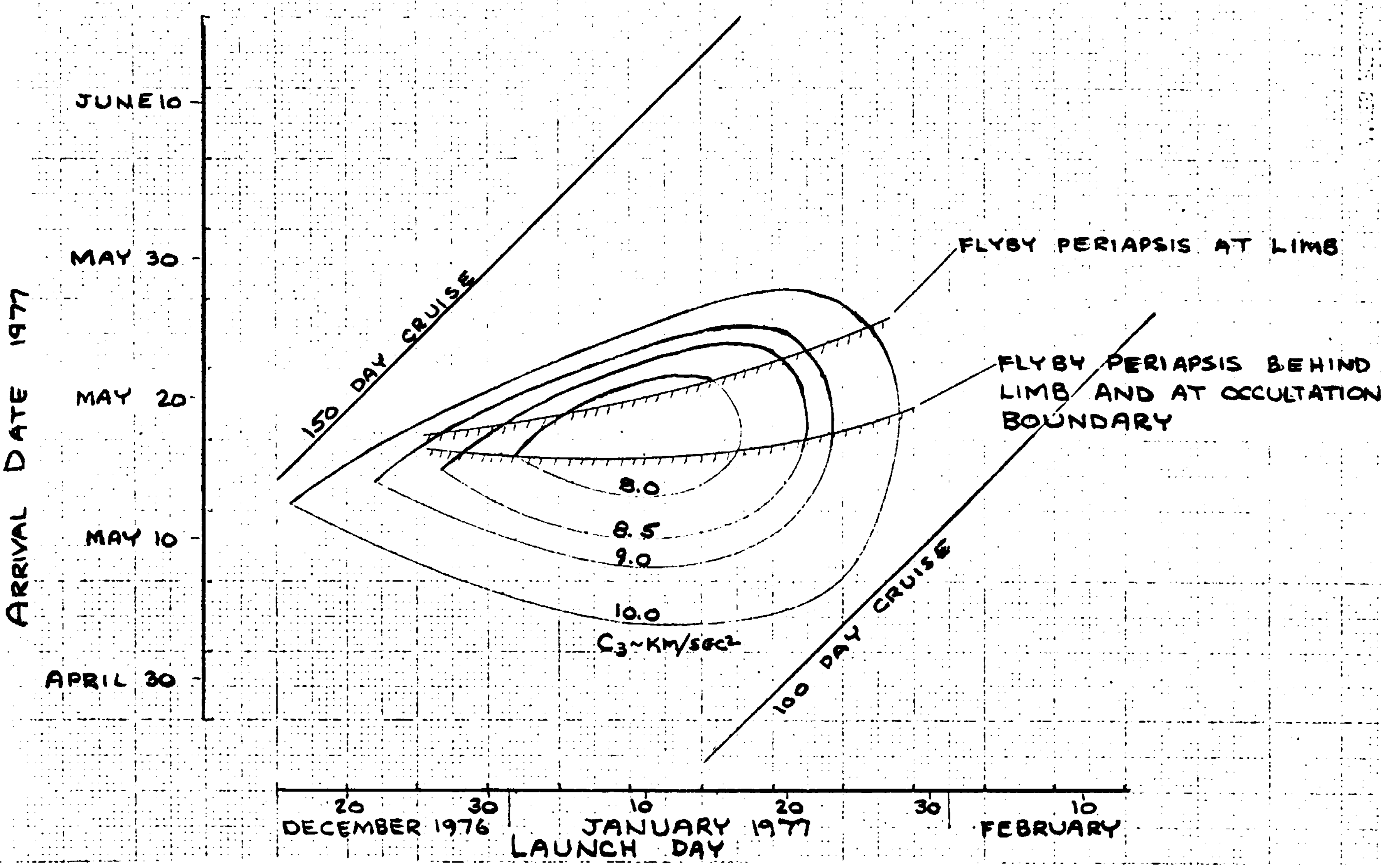
FIGURE 1

3. FLYBY VISIBILITY FROM EARTH

The bus will be occulted by Venus near periapsis. To ensure communication, periapsis must occur before occultation. The arrival geometry which influences this depends mostly on arrival date.

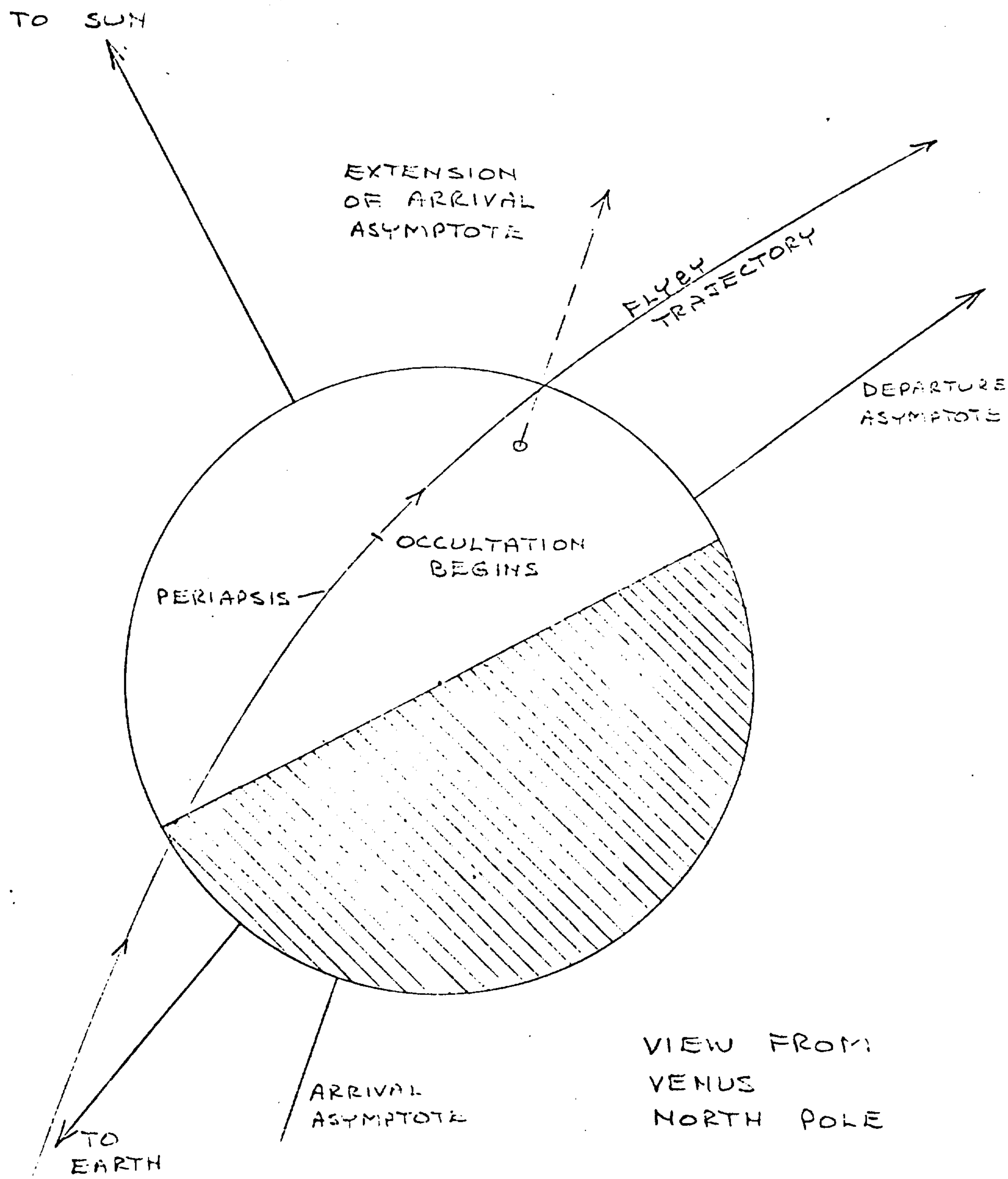
The attached Figure 2 shows the arrival date region which allows periapsis visibility from Earth. The arrival dates generally correspond to those which might be used for the second probe mission.

The latitude of periapsis will be between 65° N and 70° N (measured from the ecliptic plane).



VENUS ARRIVAL DATES WHICH PROVIDE PERIAPSIS VISIBILITY

FIGURE 2



FLYBY TRAJECTORY WITH PERIAPSIS AT LIMB

FIGURE 3

4. POST ENCOUNTER TRAJECTORY

. If periapsis is at the limb, the bus will be occulted by Venus about one minute later.

The bus trajectory will be deflected by Venus so that the departure asymptote will be within 35° of directly away from Earth, resulting in a long occultation.

The bus will not be eclipsed by the Sun during the Flyby.

After escape from Venus, the bus will be in a heliocentric orbit with periapsis at Venus and inclined about 5.5° to the ecliptic. The descending node of the post encounter orbit will be at 269° longitude (Venus' location during encounter).

The descending node of the solar equator is at 255° longitude, so the post encounter bus orbit will always be near the solar equator.

14. Report on the use and value of magnetometers in atmospheric probes. (Generated 3-7-72)

RESPONSE: 3-29-72 by C. Russell

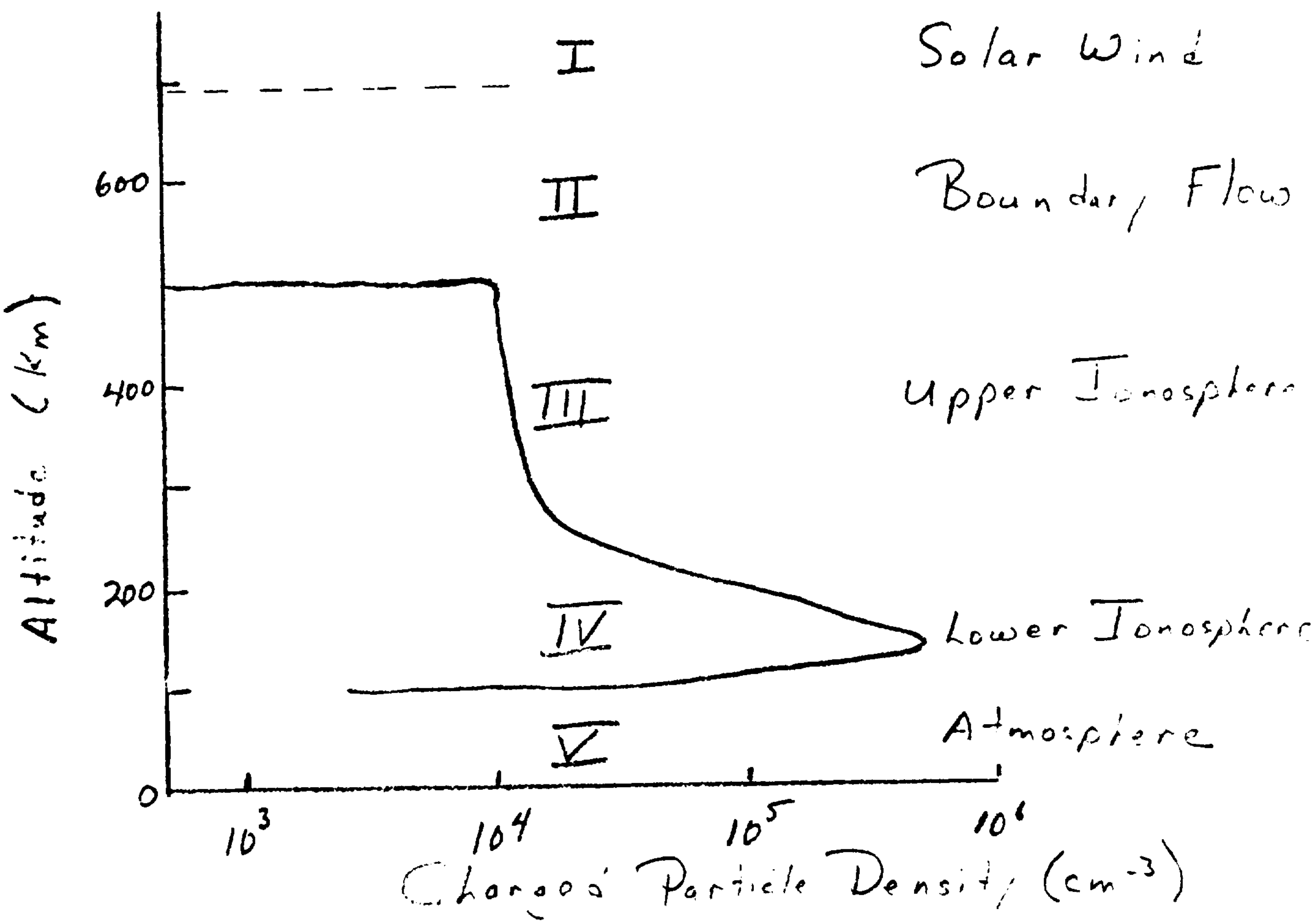
Distributed a report entitled "Pioneer Venus Magnetometer Requirements."

RESPONSE: 4-3-72

Letter from R. Goody to C. Russell.

Pioneer Venus Magnetometer Requirements

1. <u>Scientific Objectives</u>



Region I. (Solar Wind)

Measurement of $\vec{B}$ (together with $\vec{V}$) in the solar wind during encounter of other launch, provides information on the electric field applied to the Venus,—aid to understanding ionospheric current systems observed with other bus and probes. Also, it permits separation of temporal and spatial effects while other bus is in region II and III.

<u>Region II (Boundary Flow)</u>

Is solar wind electrically or magnetically connected to planetary ionosphere? Is mass being lost from neutral atmosphere due to charge exchange with solar wind? What is nature of tangential stress on region III?

<u>Region III (Upper Ionosphere)</u>

Is magnetic field strength sufficient to stand off solar wind? What currents flow in this region? Vertical and horizontal profiles of B are important and necessary to study region IV.

<u>Region IV (Lower Ionosphere)</u>

This region is inaccessible to direct measurements. We must rely on differencing fields in regions III and V. Expect strongest horizontal currents to flow in region IV.

<u>Region V (Atmosphere)</u>

Possibly the only region in which the planetary field can be measured. Two possible extremes are a predominantly dipole field like the earth's, but much weaker or a predominantly local field of remanent magnetism. If the former, then weak altitude dependence ($\sim R^{-3}$) and bus measurements can supplement probes. If the latter, strong altitude dependence ($\sim A^{-3}$) and large variation from probe to probe. Finally, comparison with measurements in region III necessary to study currents of region IV.

2. <u>Objection to Magnetometers</u>:

A. On bus.

Obj. Not necessary if magnetometer on probes.

Ans. Probes are not turned on until in lower atmosphere. Thus, probes do not duplicate bus measurements. Confusion on original panel led to a mistake on assigning magnetometer priorities. Magnetometer is essential for bus.

B. On probes - general.

Obj. Number of probes not sufficient to do spherical harmonic fit to get planetary field.

Ans. Nature of planetary field is under investigation and spherical harmonic fits are not the primary goal of this study. Probes provide radial profile too, as well as a few points scattered over surface. Probe measurements also aid in determining location and strength of currents in lower ionosphere.

Obj. Probes are magnetically unclean.

Ans. Boom can be deployed after heat shield released on large probe. Small probes are so small, that they can be built magnetically clean.

Obj. Magnetic field measurements on probes are unimportant.

Ans. There are only a limited number of methods to learn about planetary interiors on space missions: the gravitational field, the figure of the planet, surface sampling and magnetic fields. The first two will have to wait till the orbiter (and even then these may not be possible); the surface sampling will not be feasible until 1980 and then a returned sample will not be possible. The only possible measurement relating to the planetary interior on this mission is to measure the magnetic field. In view of the low overall planetary field, these measurements must be made near the surface. The measurements should be made at a variety of positions (cf. lunar measurements). The 76/77 probe mission is the only mission planned in the near future that provides such a variety of measurement sites. Further, probe measurements supplement bus measurements in defining ionospheric current systems.

C. On small probe.

Obj. Vector magnetic field measurements are not possible on small probes.

Ans. Probes will be spinning. This defines one direction. Thus at minimum the field parallel and perpendicular to the spin axis can be measured. It is highly desirable to separate the field perpendicular to the spin axis into two vector components. This requires knowledge of the time a particular line in the probe spin plane crosses a direction in inertial space. This direction might be the direction of the decelerating force on the probe if not along the spin axis or the Venus - Earth line if some radio means can be devised. Thus the measured field can be resolved into two or three components. This vector field can be filtered on board to satisfy telemetry constraints.

3. <u>Suggested Action by SSG</u>

A. Change bus magnetometer priority to 1.

B. Reconfirm specifically the importance of magnetic measurements on the probes, large and small.

C. Request project investigate the various means of determining phase of field in spin plane.

Christopher T. Russell

March 29, 1972.

HARVARD UNIVERSITY
PIERCE HALL, 29 OXFORD ST.
CAMBRIDGE, MASSACHUSETTS 02138
OFFICE OF THE DIRECTOR

CENTER FOR EARTH AND PLANETARY PHYSICS

April 3, 1972

C.J. Russell
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

Dear Chris:

My doubts about the magnetometer experiment have nothing to do with the importance of planetary magnetic field measurements. I regard the solid bulk of the planet as our ultimate objective, which cannot however be reached without first understanding the atmosphere. It would be contrary to all previous opinions expressed on this project to endanger any feature of the deep atmosphere exploration for the first of what we all hope will be a continuing exploratory series.

In the context of interplanetary exploration, magnetic field measurement is well established. However when we come to the Pioneer mission, the cost ceiling, the limited capability, the interface problems of a sealed vehicle, the environmental problems, etc., we have an entirely new situation in which need, cost, mission impact, etc. must be justified especially if other measurements are affected (as they certainly will be). To put the matter in perspective, may I remind you that at the last DPS meeting Don Rea seriously criticized the simplest measurement of all, that is temperature, as infeasible to the required accuracy. Against this background, it will need detailed assessment and analysis to justify the magnetometer experiment or we will be open to criticism as being "just like Viking."

It would be of real value for future Pioneer missions if you would make the analysis, and make the case. It is possible that the case may look strong enough for the first mission. To do so will take quite a bit of work, roughly the equivalent of writing a proposal in first draft. We would need to obtain reviews from people such as Anderson, Phinney and Wetherill. I say this because the SSG should not accept reversal of a previous considered opinion without being sure they have all the data available.

The kind of questions which bother me personally bear on the feasibility of extracting a significant result from other effects such as surface magnetization, ionospheric fields and space probe magnetization, and the impact upon the total mission. As a guide to my worries, I append a list of questions which I would like to see answered for the miniprobe subcommittee.

Sincerely,

Richard

Richard Goody

Questions for magnetometer experiment.

1. Why it is important to measure the planetary magnetic field and why are several locations desirable?

2. What levels of planetary magnetic field are significant?

3. Are these levels likely to be distinguishable through surface rock magnetism? Is there any fundamental significance in surface magnetism as opposed to planetary magnetism from a planetological point of view?

4. At known levels of ionization and the intense winds postulated to support night-time ionization, what is the probable ionospheric contribution to the surface magnetic field? How will it probably vary in space and time?

5. How will the ionospheric field be eliminated? Two different probes are involved (bus and one entry probe) and these enter at different geographic locations.

6. What requirements are placed upon probe magnetic cleanliness? Is a boom required? The three entry probes are subject to different mechanical strains and thermal histories , how would this influence magnetic cancellation procedures? What problems are involved in comparing bus and probe instruments? Which is the best procedure: cleanliness; boom; or cancellation?

7. What kind of instrument?One or three axis? How will orientation be determined? Data rate?

8. What is the combined effect of 6 and 7 on spacecraft weight, cost and capability? What technical problems will have to be solved to have a useful system.

9. Is there any point in installing a one-axis magnetometer with no precautions of the nature of those described under 6?

10. Would it be more desirable to leave magnetic measurements to a special geo-science package on a later mission? The answer to this question relates to the answers to 8 and 9.

RG/dc/4-3-72.

15. The Pioneer Venus Project is to identify the interface problems and cost impact of magnetometers on the probes and probe bus.

RESPONSE: 3-29-72 by R. Christiansen

Distributed a report entitled "Considerations Relating to Spacecraft Magnetic Cleanliness."

RESPONSE: 4-24-72 by R. Christiansen

Magnetometer instrument types which might be considered for the probes and probe bus have been identified and described in terms relating to the spacecraft interface. A preliminary assessment of interface complexity, system impact, and related considerations is being prepared.

RESPONSE: 6-5-72 by R. Chistiansen

The project has earlier provided information based on Pioneer experience which indicated that an extensive magnetics design control and test effort, aimed at achieving a background field level at the sensor of $< 1\gamma$, represented a cost to the spacecraft program of approximately 5% of the total (spacecraft design, development, test, production).

The Project presented additional information for discussion during the SSG April meeting at Ames Research Center. This information included assessments of the integration complexity and impact associated with magnetometers aboard the large and small probes, and the probe bus. The findings, as reviewed, were the following:

(a) Small Probe - An analysis of the baseline small probe payload and the materials involved in the probe body construction indicates no basic incompatibilities with achieving a low background magnetic field for the small probe. Further, this background should be stable and predictable for conditions within the probe shell, allowing the use of an internally mounted sensor. The rotation of the probe body during descent would provide an additional aid in separating the probe-induced field from the ambient. Instruments based on a minimum measurement approach have been conceptually sized in the 1-2 lb range. With these considerations, it was concluded that the small probe could accommodate a magnetometer with relatively modest impact on the baseline probe design.

(b) Large Probe - A magnetometer aboard the large probe poses a more severe compatibility and integration problem. The chief difficulty arises in recognition of the types of priority instruments which will comprise the large probe payload; in particular the mass spectrometer. The level and variability of the magnetic fields associated with these instruments make it impractical to consider an internally mounted magnetometer sensor. Conceptually, a relatively

15. (Continued)

simple sensor boom might be devised which would deploy with separation of the probe forebody. Any detailed consideration of this approach would need to be based on a specific probe system design and its operating constraints. Thermal control for the boom mounted sensor during descent might be a problem area with this design.

It is judged that this instrument represents significant impact to the large probe in three main areas:

(1) An extensive magnetics control effort for both the probe system and payload would be required.

(2) In order to achieve a compatible magnetic environment, it would be necessary to impose constraints on the magnetic character of other payload instruments.

(3) A sensor boom would most likely be required.

(c) Probe Bus - Integration of a magnetometer instrument with the probe bus presents many of the same difficulties discussed for the large probe, including the near certain requirement for a sensor boom. Tradeoffs of boom length versus spacecraft magnetics control levels can be made for the specific spacecraft design to achieve some minimum integration cost approach. Regardless of the particulars of this tradeoff, however, it can be assumed that the incorporation of an additional appendage will have appreciable effect on the design of a spin-stabilized probe bus, and is therefore regarded as a significant impact item.

CONSIDERATIONS RELATING TO SPACECRAFT MAGNETIC CLEANLINESS

The following is a brief discussion of the activities and practices involved in producing a spacecraft with magnetic properties which are compatible with a magnetometer sensor designed to measure low level ambient magnetic fields.

1. Spacecraft-Cleanliness Specification.

   The requirements for magnetic cleanliness generally are expressed as limits on the intensity and variability of the field at the instrument sensor mounting location. As an example, the magnetic specifications for the recent Pioneer 10 spacecraft were:

   a. 0.03 γ due to the energized spacecraft (stray fields)

   b. 0.04 γ due to remanence after demagnetization

   c. 0.25 γ due to remanence after an exposure to a 25 gauss field.

   These requirements were successfully met with the use of a 19 foot boom for remotely mounting the magnetometer sensor. Achieving a 0.2 γ or less background level at the sensor is representative of programs with low magnetic requirements.

2. Spacecraft Cleanliness Criteria and Methods.

   The present approach to achieving a magnetically clean system requires that all elements of the spacecraft, including experiments, undergo a disciplined program to eliminate or reduce both the spacecraft remanence and stray field components. This effort includes the following:

   a. Establishment of acceptable magnetic threshold levels for parts, assemblies and the spacecraft at initial design.

   b. Selection of spacecraft materials for the lowest attainable magnetic signatures.

   c. Use of parts (both electronic and electro-mechanical) with the least amount of ferromagnetic material.

   d. Modification of parts and components to reduce remanence.

   e. Elimination of devices which employ permanent magnets whenever possible.

   f. Provision for a single point ground of all electrical elements to minimize stray fields.

Many materials commonly considered in industry to be non-magnetic have been found to be magnetically unacceptable for spacecraft use. Many transistors have nickel cases and leads which make them highly magnetic. Where possible a non-magnetic nickel-silver alloy case material is substituted and the leads clipped short before installation.

The process of selecting suitable parts will not eliminate all magnetic sources from a spacecraft. Some vital parts require permanent magnets. Other parts use a highly-permeable material, and a few devices make extensive use of ferrites and ferromagnetic material. An arrangement of the magnetic parts within an assembly can be chosen, however, so that the resultant field is minimized. When a number of identical parts with large permanent fields, such as latching relays are used, they can be arranged so that the magnetic fields will cancel each other. In the case of traveling wave tubes, the field can be reduced by attaching small permanent magnets to the tube. Shielding (enclosing the disturbing part in a container of highly permeable material) can be employed to control certain field producing elements. However, because shielding can affect the shielded parts function, it is generally avoided unless the resulting field reduction clearly outweighs such disadvantages.

Magnetic fields induced by currents can usually be controlled by careful wiring of the assemblies. It is almost impossible, however, to avoid leakage from transformers and inductors. The leakage can be reduced by employing toroidal transformers and inductors and by using extreme caution in the mixing of these parts. Magnetic fields caused by current loops of 10 ma or more within assemblies can be reduced by using leads of twisted pairs.

The wiring harness between assemblies and stray ground current paths in the structure can be minimized as sources of magnetic fields by careful design which limits the number and closed areas of loops and uses a single point grounding system in the spacecraft. Magnetic interference caused by currents flowing in solar cell arrays can be controlled by a backwiring technique in which the current return wires are routed directly behind the solar cells and thus tend to cancel the effects of the outgoing current.

When the irreduceable minimum signature has been achieved, it is still usually necessary to remote the magnetometer sensor from the body of the spacecraft by means of a boom. The field that the magnetometer sees varies inversely as the cube of the distance between the spacecraft and the magnetometer sensor. The practical boom length is limited by spacecraft weight and balance requirements (conditions before and after deployment), deployment dynamics and boom design complexity. Trade-offs are therefore required between the boom construction, reliability, and the need to locate the magnetometer instrument away from the spacecraft magnetic sources.

3. Testing.

Tests are performed throughout the hardware program as a means of control and confirmation of the desired results. To assure the use of initially clean hardware, magnetic screening is performed on all piece parts, wire, fabricated elements, etc., at the time of incoming inspection. Assemblies are tested individually as part of qualification and acceptance. These tests include measurements of the induced, stray and permanent magnetic fields of the assembly before and after exposure to a 15 to 25 gauss field. Testing after demangetization indicates the change which might occur in the magnetic field of the assembly during testing and launch. After part and assembly testing, the assembled spacecraft is tested. The system tests are performed in a controlled low field, stable ambient environment and include measurement of the dc magnetic fields of the non-operating spacecraft and of the stray fields associated with all operating modes of the spacecraft. Mapping of the dc magnetic fields is accomplished through measurements taken at specified distances along the radial from the spacecraft's center. After the deperm test of the spacecraft, flux recorders are used to monitor possible accidental exposure to magnetizing fields during transport, handling and launch preparations.

4. Science Payload Magnetic Cleanliness Criteria.

The procedures applied to the spacecraft elements must also be used in the design and fabrication of the science instruments. Here the task is sometimes quite difficult because many instrument functions are designed around the use of magnets or magnetically permeable materials.

5. Costs.

The experience of previous spacecraft programs with low magnetic signature requirements shows that up to 5% of the total spacecraft cost can be traced either directly and indirectly, to achieving these requirements. In the atmosphere of a low-cost program it will be necessary to consider some alternatives to the current practices. Some areas which appear worthy of further investigation are:

a. Elimination of individual parts screening on the basis that our experience will allow us to deal with classes of parts with predictable results.

b. Reduction of individual component and assembly testing in favor of a more emphasized analytical prediction effort based on previous program experience.

c. Acceptance of a higher remanent magnetic field threshold for the spacecraft, but provide more accurate predictions for in-flight levels to enable discrimination of ambient from spacecraft fields.

These and other considerations will be further developed and examined as science requirements are identified and the spacecraft design studies proceed.

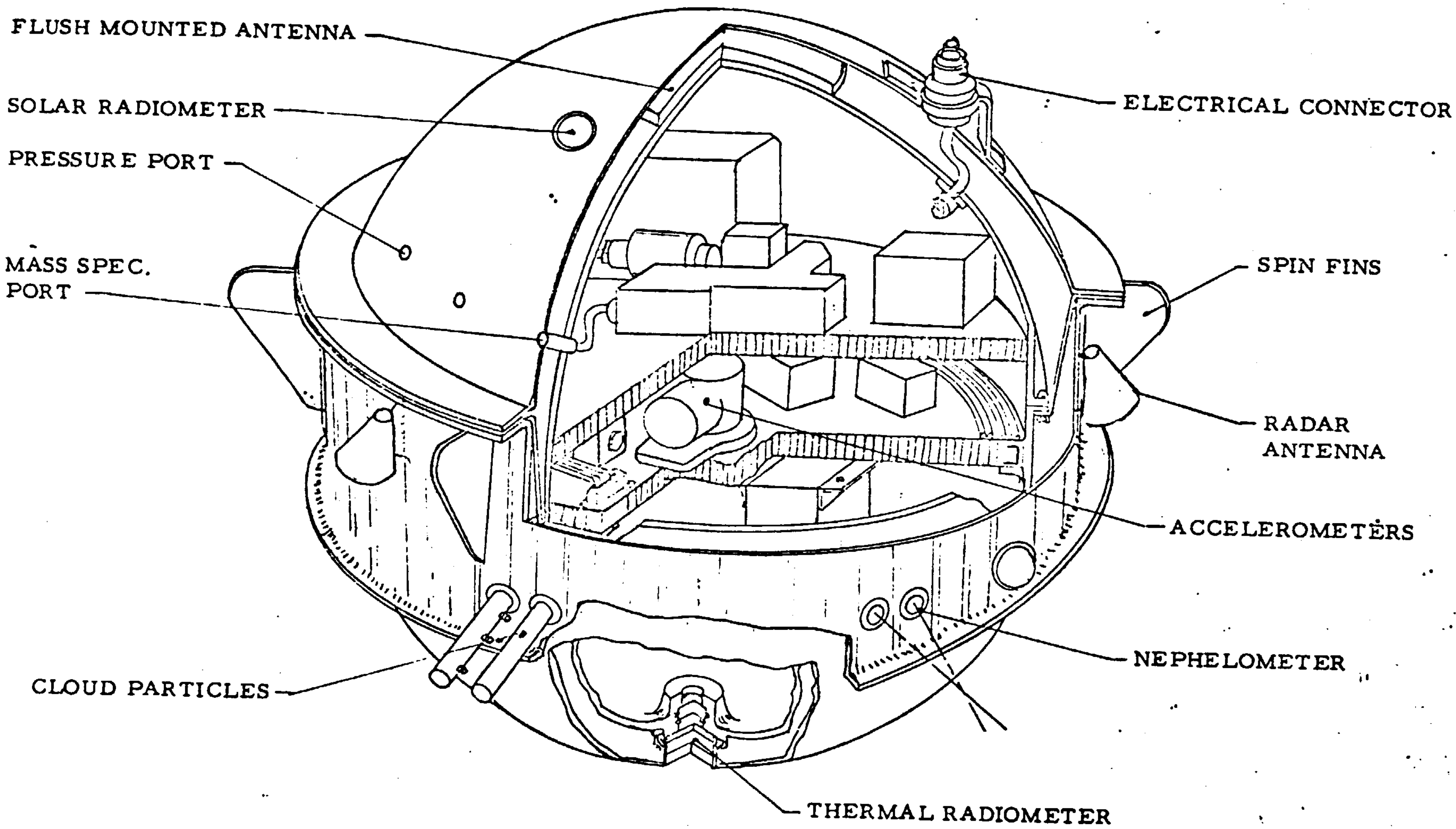
16. Report on the Aerodynamic design of the probes.
(Generated 3-7-72)

RESPONSE: 3-24-72

Mr. T. Canning discussed the aerodynamic design of the probes. He also narrated a short movie that demonstrated the stability of a "burbled" sphere. The charts used in his presentation are attached.

LARGE PROBE PRESSURE VESSEL

(TERMINAL DESCENT CONFIGURATION)



TOP VERTICAL

ATMOSPHERE PROPERTIES	&	MISSION CONSEQUENCES
HIGH ALTITUDE DENSITY		START OF BLACKOUT
		OVERHEAT TURBOPAUSE INSTRUMENTS
HIGH ALTITUDE SCALE HEIGHT		BLACKOUT DURATION
		HEATING PROFILE
		DECELERATION PROFILE
		PARACHUTE DEPLOYMENT CONTROL
CLOUD THICKNESS		SAMPLING FREQUENCY
WIND SHEAR AND TURBULENCE		SAMPLING FREQUENCY
		COMMUNICATION LINK INTERFERENCE
MAJOR CONSTITUENTS TRACE MATERIALS		CONDENSATION ON WINDOWS AND IN SAMPLING SYSTEMS
		CORROSION
		R.F. ABSORPTION
LOW ALTITUDE PRESSURE–TEMPERATURE		PAYLOAD SURVIVAL
		DESCENT STAGING
		REFRACTION

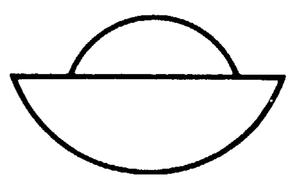
TOP VERTICAL

SPIN RATE

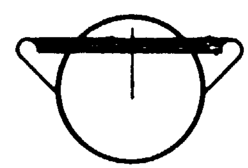
$$\ddot{\phi} = \frac{Ab}{2}\,\frac{\rho}{2}\,V^2 \left[C_{L_\delta}\,\delta - C_{l_p}\,\dot{\phi}\,\frac{b}{2V} \right]$$

FOR $\ddot{\phi} = 0$

$$\dot{\phi} = \frac{2\,C_{L_\delta}\,\delta}{C_{l_{\dot{\phi}}}\,b}\,V$$



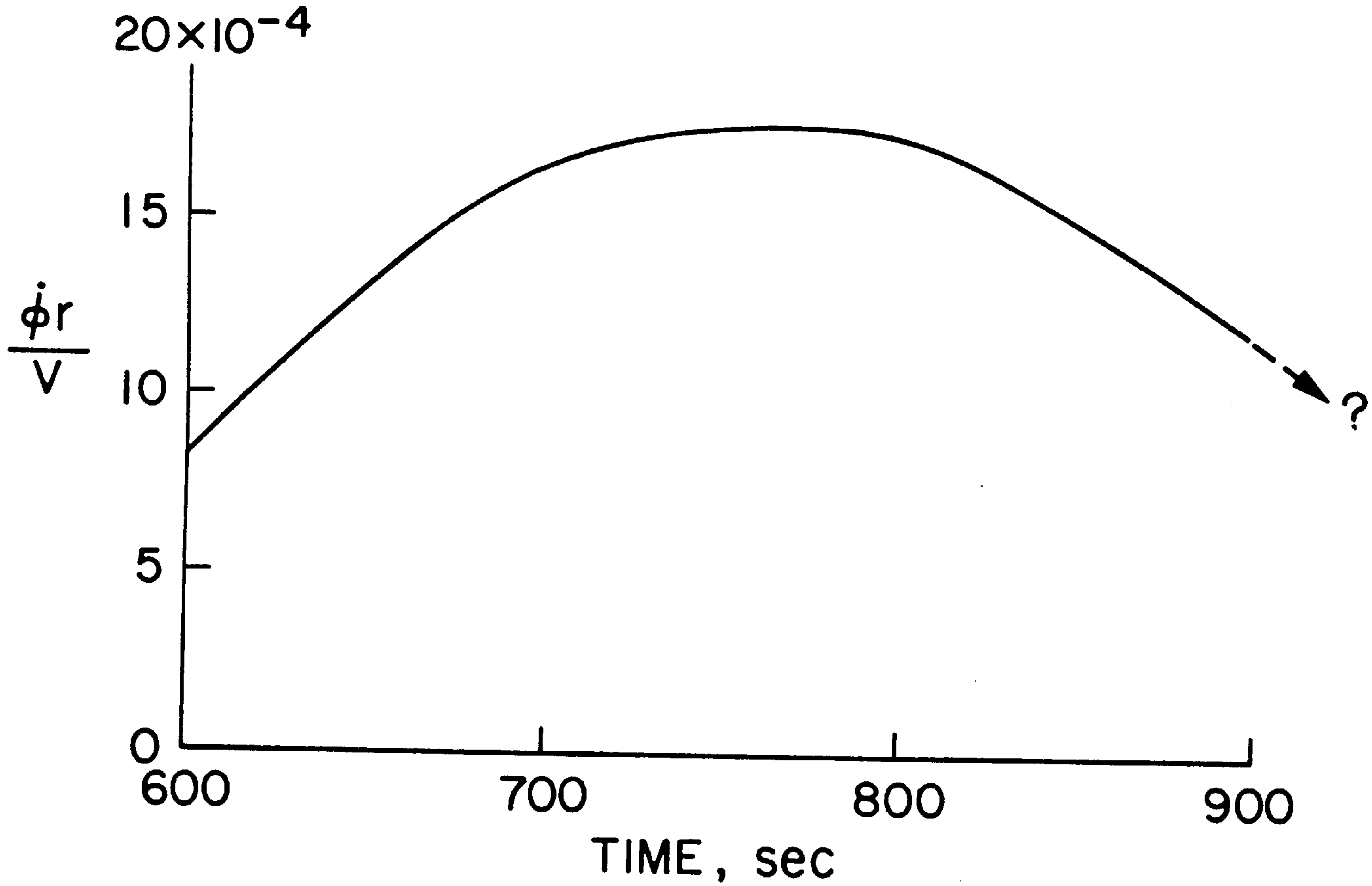
UNCERTAIN SPIN



PREDICTABLE SPIN

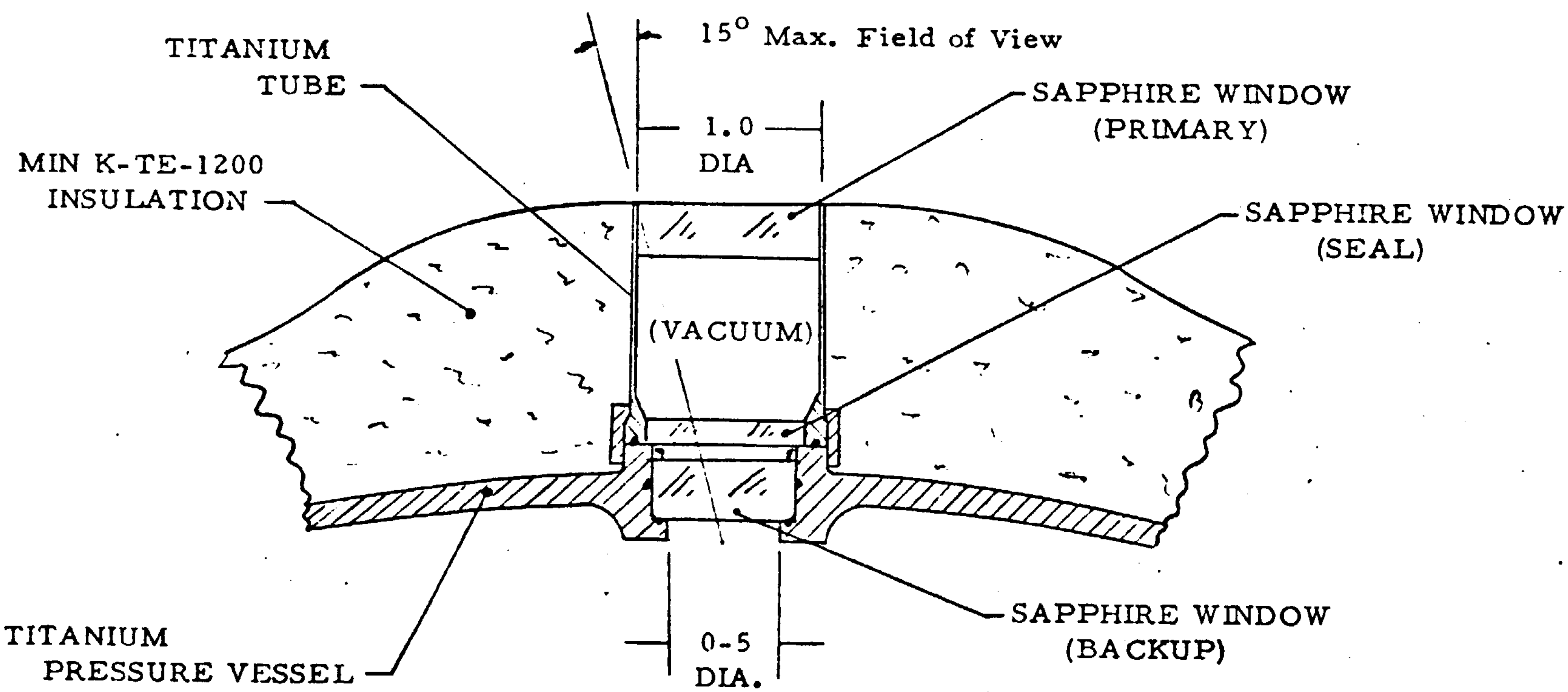
TOP VERTICAL

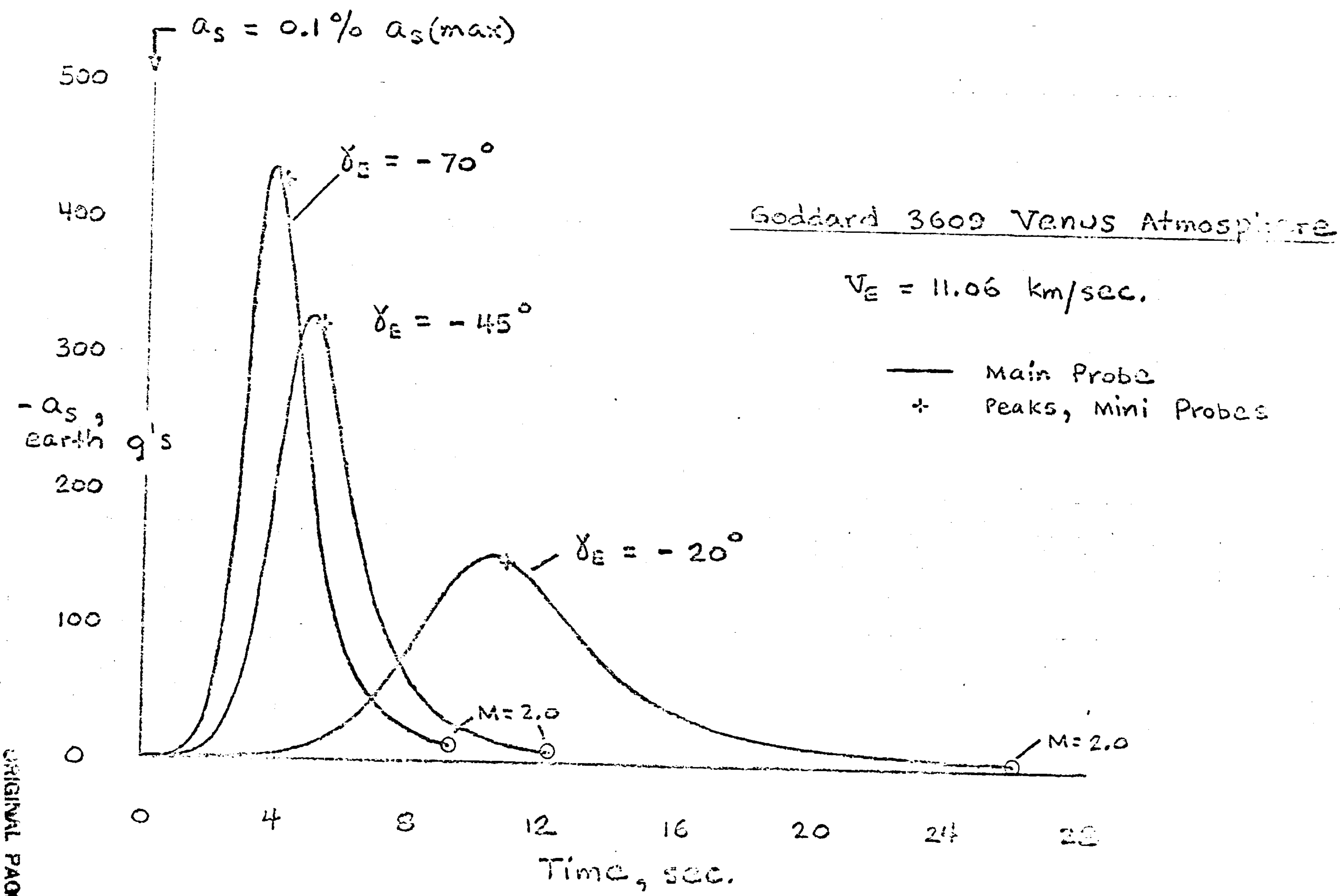
ROLL RATE HISTORY
PAET



TOP VERTICAL

OPTICAL PORT DESIGN CONCEPT





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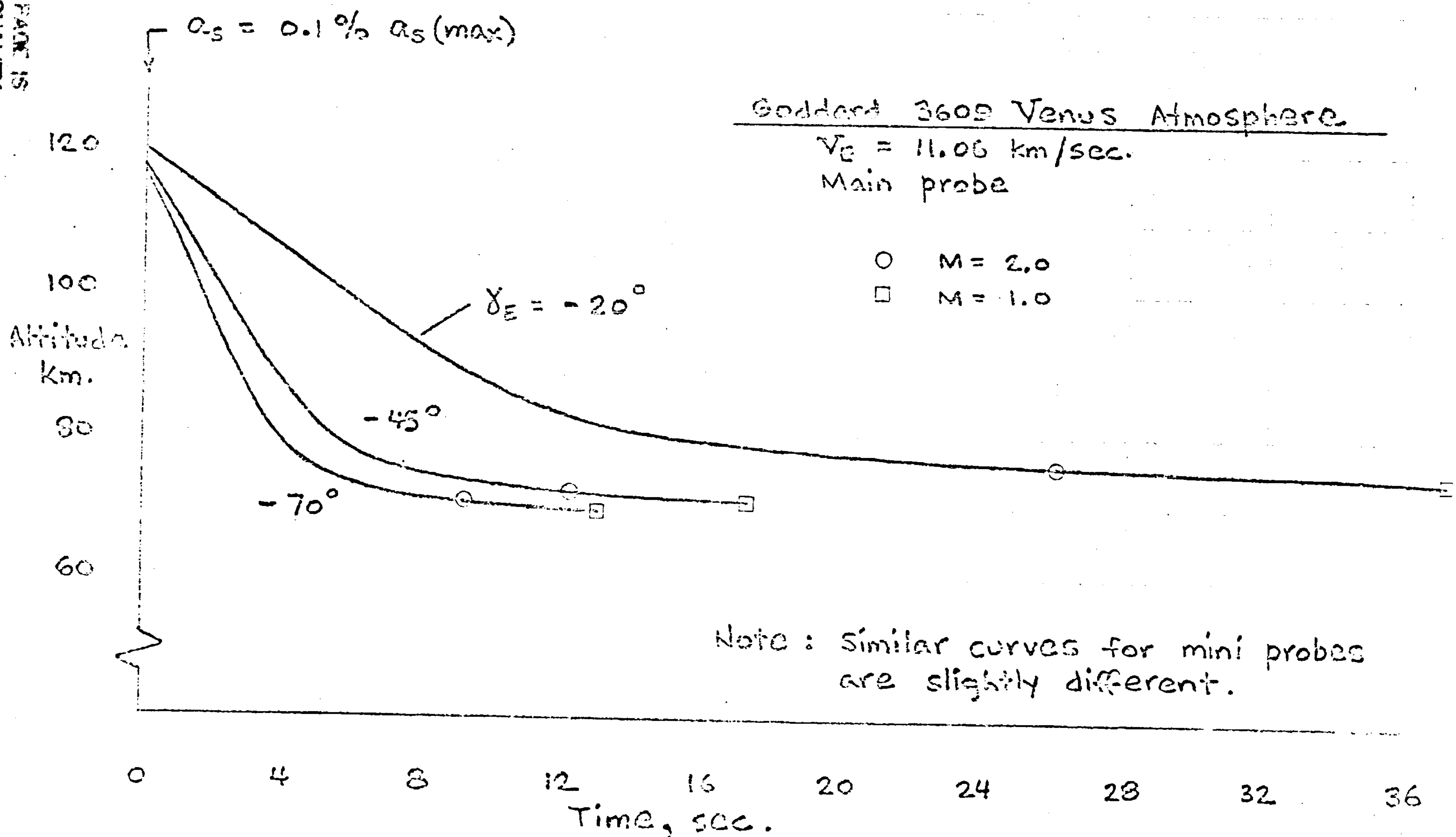
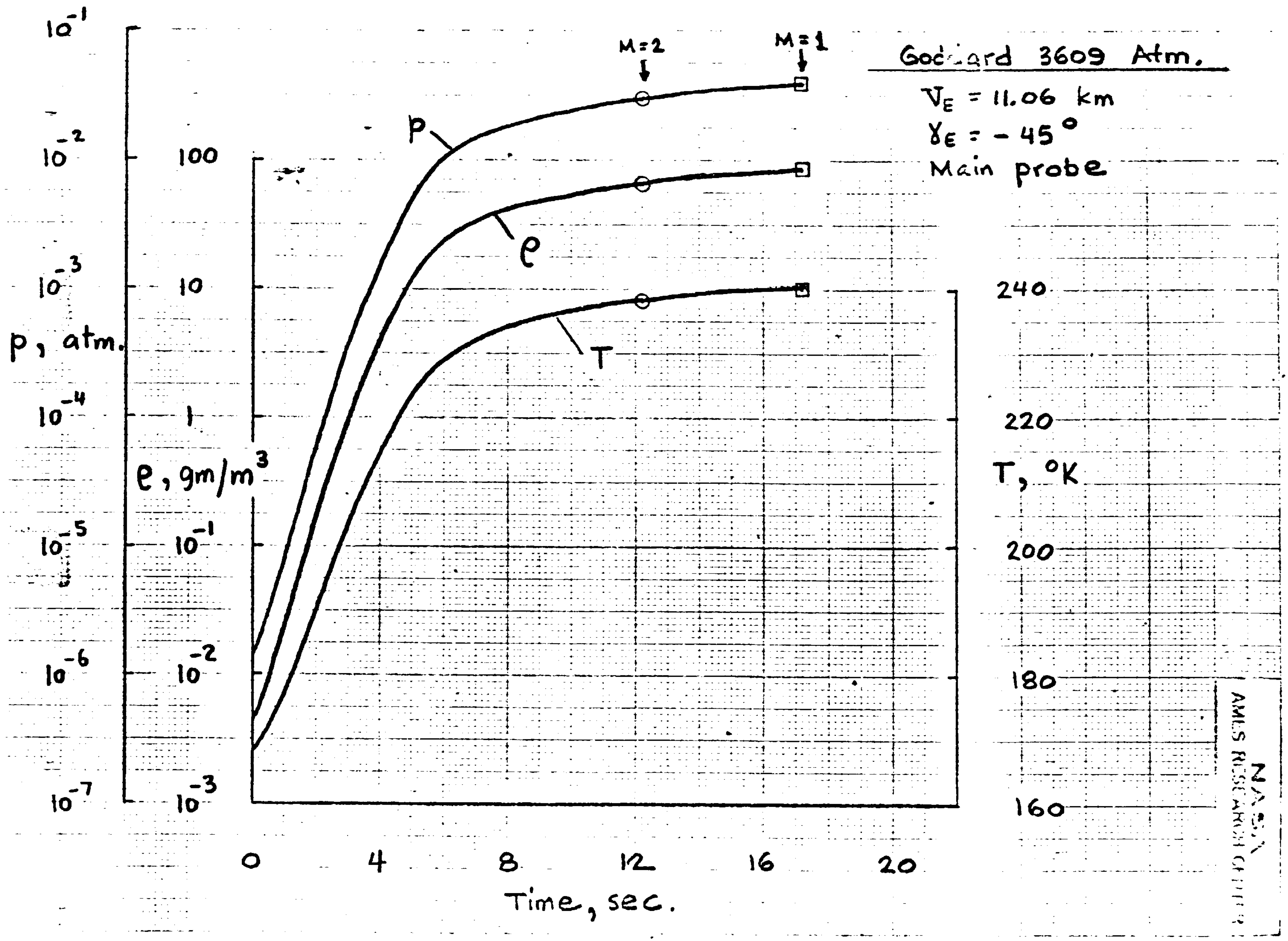
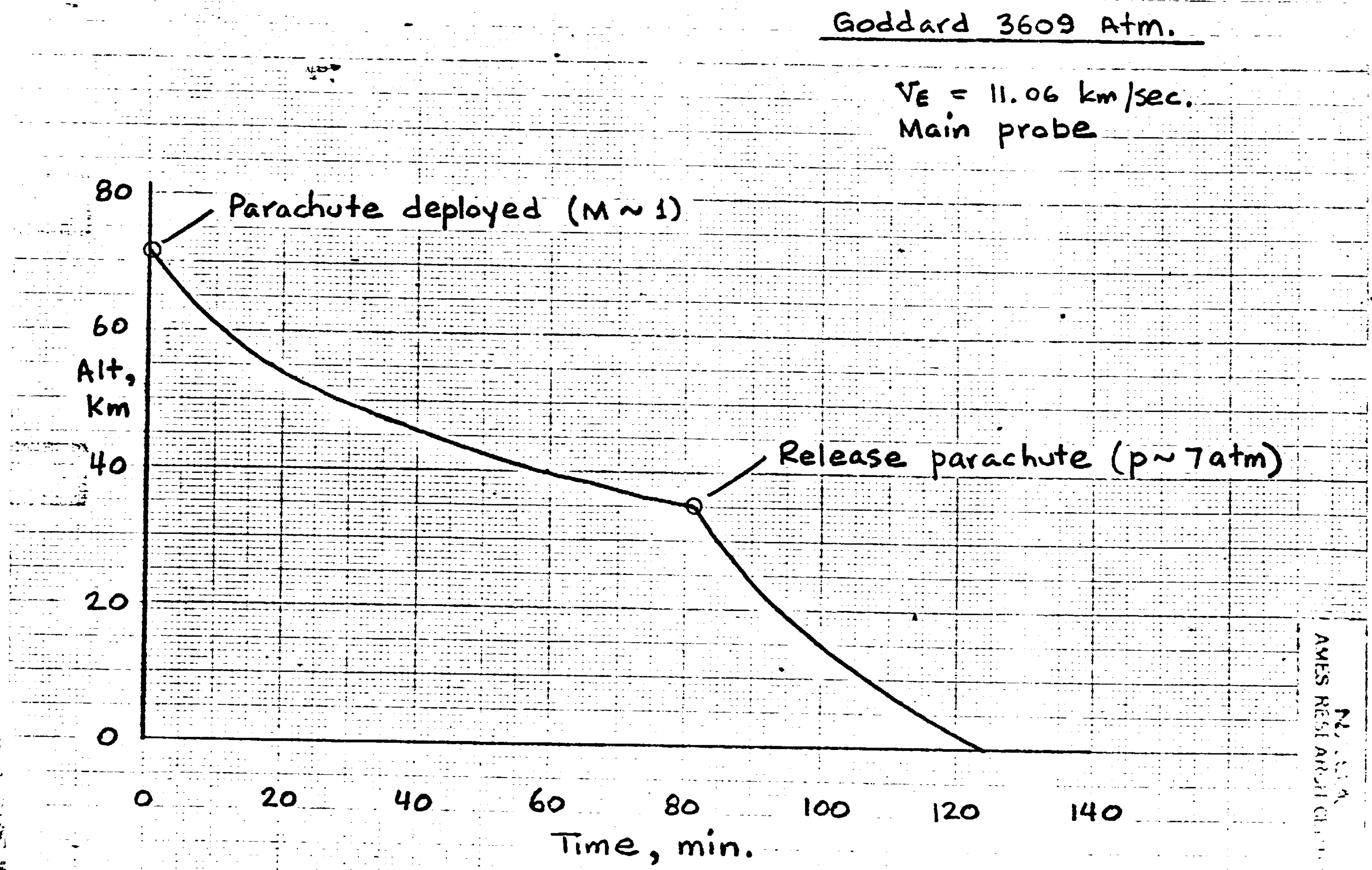
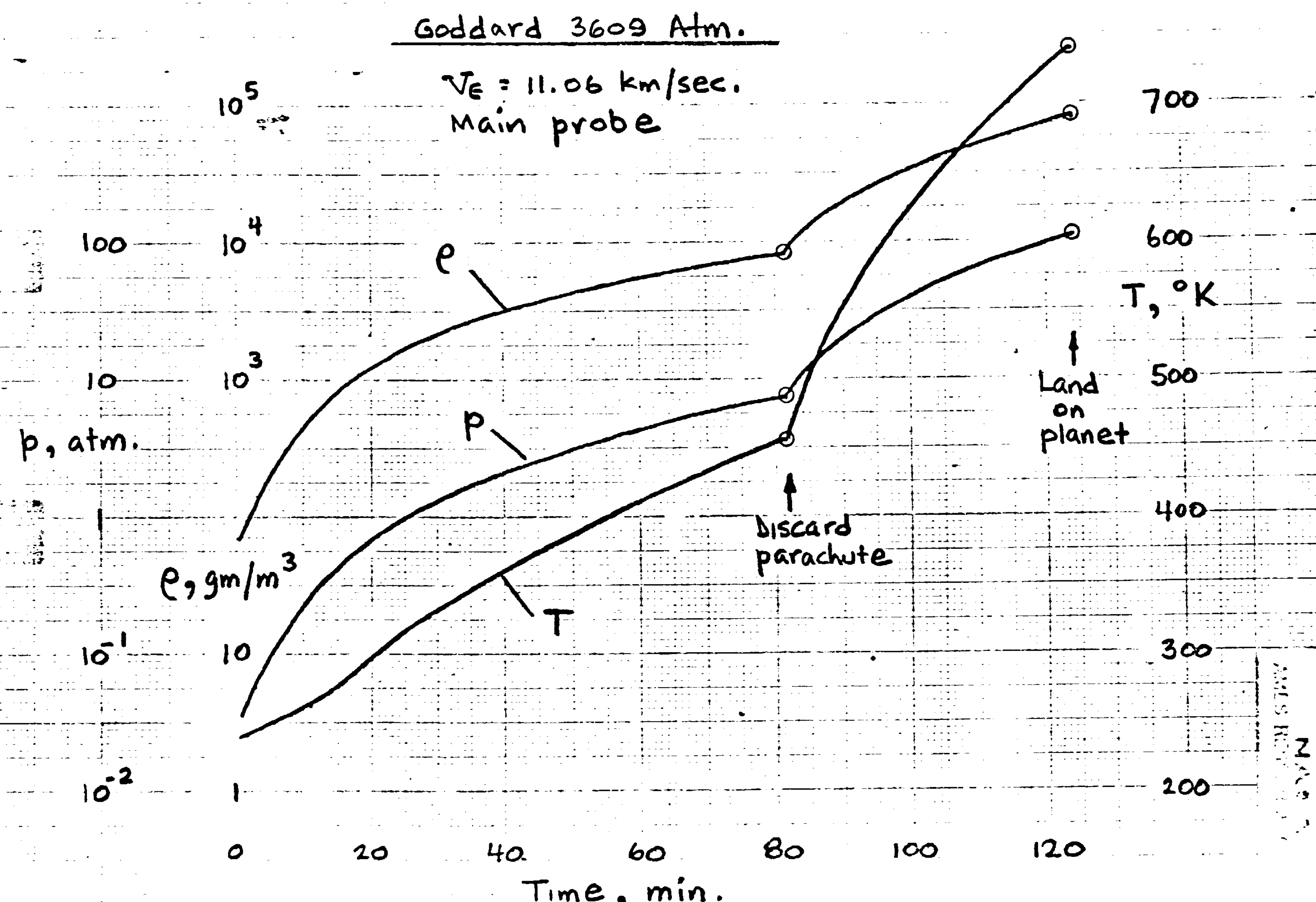
OF POOR QUALITY


$a_s = 0.1\%\ a_s(max)$
Goddard 3609 Venus Atmosphere
V_E = 11.06 km/sec.
Main probe
○ M = 2.0
□ M = 1.0
$\gamma_E = -20°$
$-45°$
$-70°$
120
100
Altitude
Km.
80
60
Note : Similar curves for mini probes are slightly different.
0
4
8
12
16
20
24
28
32
36
Time, sec.

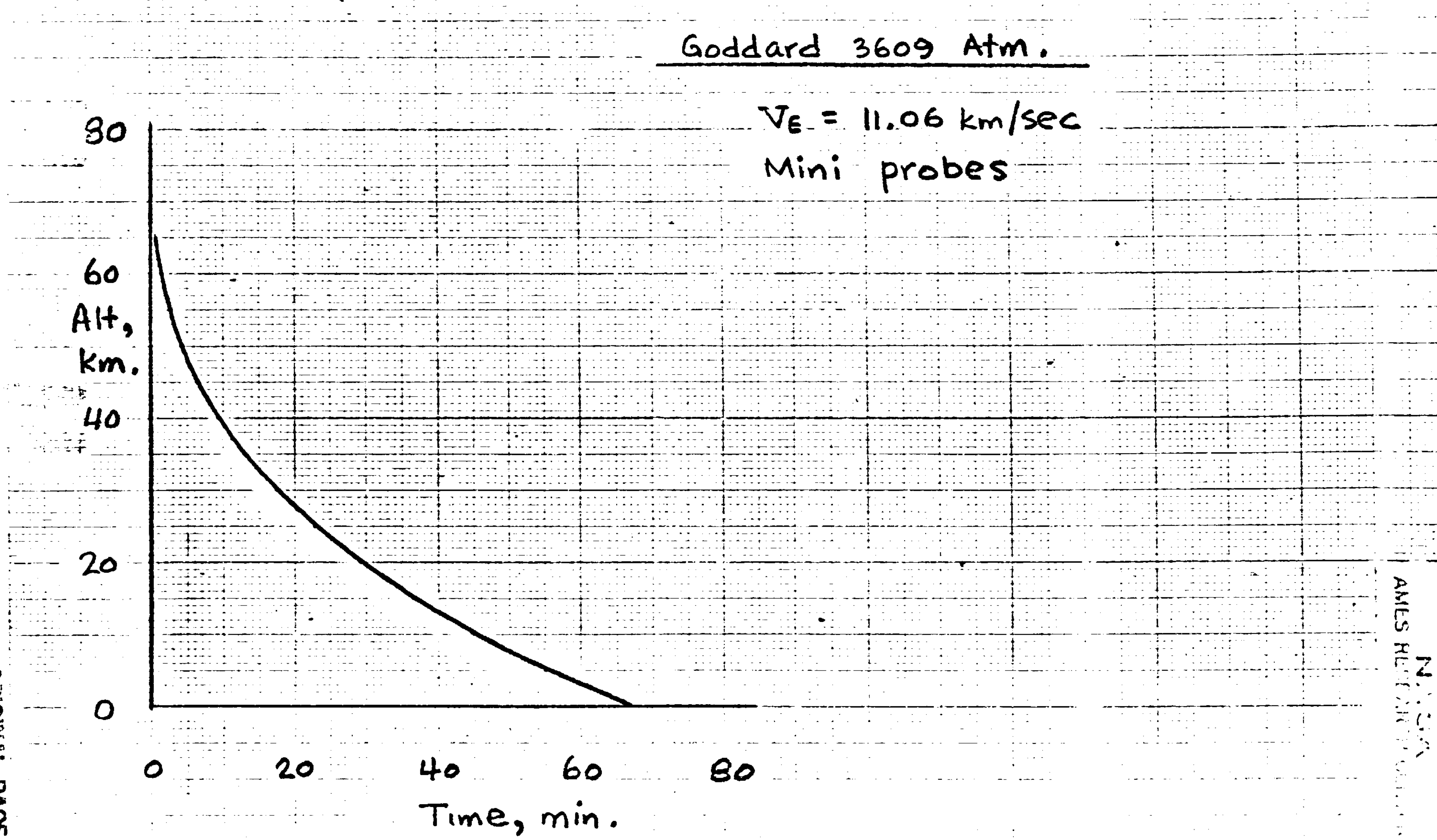


Goddard 3609 Atm.
V_E = 11.06 km
γ_E = -45°
Main probe
M=2
M=1
p
ρ
T
p, atm.
ρ, gm/m³
T, °K
Time, sec.
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
100
10
1
10^{-1}
10^{-2}
10^{-3}
240
220
200
180
160
0
4
8
12
16
20
NASA
AMES RESEARCH CENTER


Goddard 3609 Atm.
V_E = 11.06 km/sec.
Main probe
Parachute deployed (M ~ 1)
Release parachute (p ~ 7atm)
80
60
Alt, km
40
20
0
0
20
40
60
80
100
120
140
Time, min.



Goddard 3609 Atm.
V_E = 11.06 km/sec.
Main probe
p, atm.
100
10
1
10^{-1}
10^{-2}
ρ, gm/m³
10^5
10^4
10^3
10
1
ρ
p
T
Discard parachute
Land on planet
T, °K
700
600
500
400
300
200
0
20
40
60
80
100
120
Time, min.



Goddard 3609 Atm.
V_E = 11.06 km/sec
Mini probes
Alt, km.
80
60
40
20
0
0
20
40
60
80
Time, min.

17. The Pioneer Venus Project is to perform entry trajectory studies based on different models for Venus winds.
(Generated 3-29-72)

RESPONSE: 4-24-72 by T. Canning

Effects of Atmospheric Motion on Probe Descent

a. Steady winds are the simplest atmospheric motions in terms of flight influence. Horizontal wind components simply introduce lateral translation of the probe but have no effect on descent or stability. Vertical wind components add directly to the descent velocity, so the altitude history is directly influenced.

(1) b. A steady wind shear (constant derivative of horizontal wind speed with respect to vertical distance traveled) introduces a very small inclination of the descending system and is most severe for a parachute - suspended capsule. The inclination, α, can be approximated by:

$$\alpha = \frac{1}{2\, mg_{♀}} \quad \rho_\infty \quad \frac{dW}{dZ}^{2} \quad \ell^2 \, A \, C_n$$

where $mg_{♀}$ is the capsule weight

ρ_∞ is ambient density

$\frac{dW}{dZ}$ is the wind shear

ℓ is the distance between parachute canopy and the probe capsule

A is the capsule reference area

C_n is a non-dimensional aerodynamic coefficient

A wind shear of 10 meters/sec km would result in an inclination of about one-tenth degree.

c. The effect of a "sharp edged gust"* (horizontal wind) can be visualized by considering the response to an impulsively started wind. If we ignore the parachute mass (its own ballistic coefficient is enormously less than that of capsule), we can see that as a first approximation the first swerve will reach an inclination α of

$$\alpha = \tan^{-1} \frac{\Delta W}{U}$$

---

(1) The analysis in this paragraph is over-simplified. More defensible results, arriving at the same conclusion, have been added to this series of action items.

* Dr. Goody felt that one should not be too concerned about any sharp-edged gust. He felt that the parachute specifications are good for Earth they should be okay for Venus, since the Venus atmosphere is not as disturbed as the Earth's.

17. (Continued)

Just before parachute release $U \approx 4 \frac{M}{Sec}$ so a 1 m/s sharp-edged gust yields

$$\alpha = \tan^{-1} \frac{1}{4} \approx 15°$$

This is a violent response but is greatly modified by response of the capsule to side loads from the displaced parachute and by lateral restraint on the canopy's motion by the capsule's inertia. Clearly, the motions will not be small with this strength of disturbance. Amplitudes and damping of such systems are difficult to characterize in straightforward terms; recourse to the extensive literature on parachute development and performance is required. Early evidence suggests that systems yielding excursions less than 5° in Earth descent are easily achievable. This art will be further examined by John Givens to determine how similar performance can be attained in the atmosphere of Venus.

RESPONSE: (6-5-72)

The performance and stability of parachute-payload systems will continue to be studied (largely literature) throughout the systems definition phase. No further reports are anticipated during the tenure of the Pioneer Venus Science Steering Group.

17. (Continued)

ADDENDUM:

A more rigorous analysis of descent through a gradual linear wind shear shows that

$$\alpha \approx \frac{Ac}{A_p} \frac{CDc}{C_{Dp}} \frac{dW}{dZ} \frac{\ell}{V}$$

α is the trim position away from vertical

Ac and Ap are areas of capsule and parachute, respectively

CDc and CDp are corresponding drag coefficients (roughly equal)

W is horizontal component of wind

Z is altitude

ℓ is shroud line length

V is descent speed

Inserting reasonable values into this expression, we get

$Ac/Ap \approx 10^{-2}$

$CDc/CDp \approx 1$

$dW/dZ \approx 0.1 \ \frac{m}{sec,m}$

$\ell = 10$ m

$V = 4$ m/sec

$\alpha \approx 0.15$ deeg.

18. The Pioneer Venus Project is to perform a feasibility study for downward optical viewing from the small probe. Included is an investigation of discarding the heat shield after entry.

RESPONSE: 4-24-72 by T. Canning

Provision of forward "visibility" from the mini probe can be obtained after entry by:

a. Deployment of boom mounted sensors or windows from base region to "look around" remaining heat shield.

b. Jettisoning entire heat shield in a manner like that used for maxiprobe after deceleration.

c. Jettison plugs (shutters) in the heat shield to expose windows after deceleration.

Advantages of "a" are simplicity of concept, ease of keeping window clean during entry.

Disadvantages of "a" are long optical path for inboard sensors (or poor environment for outboard) actuation requirement after entry, sealing against environment, difficult location for "de-fogging" heater on window.

Advantages of "b" are that once this track is taken, all instrument deployments are probably simplified and window de-foggers are protected. Frontal area may be greatly reduced so as to reduce descent time - perhaps 30%. Thermal control is eased - perhaps by 2#.

Disadvantages of "b" are complex separation, actuators, and ejection system. A weight penalty of over 4# for a parachute or about 2# for a mortar or pyrotechnic ejection would probably more than offset thermal system weight reduction.

Advantages of "c" are relative simplicity and positive action. If small shutters built into heat shield - aeroshell and forced open by pyro actuators each aperture can be opened for less than 1/2#, perhaps 1/4# , as was done for PAET thermocouple. Good optical efficiency and minimum design impact are features.

Disadvantages of "c" are that the window would be recessed and would be prone to dust and condensate collection.

These factors will be studied in greater detail throughout the consideration of downward looking mini probe instruments by Tom Canning and Nick Vojvodich.

RESPONSE: 6-5-72 by T. Canning

Further thought and examination has resulted in no change in our estimate of the cost of downward viewing from the miniprobe.

19. The Pioneer Venus Project is to study the problems associated with penetrations through the probe shell. These penetrations will include instrument windows, the mass spectrometer inlet, temperature and pressure probes and electrical connectors.
(Generated 3-29-72)

RESPONSE: 4-24-72 by N. Vojvodich

The power required to combat window fogging on the initially cold capsule windows was evaluated briefly by calculating the heater power necessary to raise the temperature of the outer window in a double-glazed installation slightly faster than the ambient temperature is raised. The power applied must slightly exceed the sum of that required to store energy in the pane and that required to overcome conduction losses into the window frame.

q stored = Heat capacity X temperature rise rate

q frame = Conductance X temperature difference
+ heat capacity X temperature rise rate

At parachute release, a 2.5 cm window, 1 cm thick, requires about 2 watts for storage and 3 watts for frame losses.

A study of alternative designs to reduce this severe penalty is being pursued. An elaborate design which may reduce the required power to less than 1 watt is being studied to obtain a quick assessment of the prospects for low power.

Thermal Penetrations

Heat conduction through typical installations which must penetrate the insulation will be assessed for each penetration and, in effect, "charged" to the instrument or function which it serves.

RESPONSE: 6-5-72 by N. Vojvodich

At the request of the SSG, the problems associated with providing clear, uninterupted access to the atmosphere of Venus by means of windows, have been assessed. Sources of information have included: (1) Vendor supplied data, (2) contractor responses to the Pioneer-Venus system design RFP for a Phase B Study and (3), work initiated and being carried out by the Ames Pioneer Venus Project Office. Summarized below is a status statement on the existing data base, analytical work performed to date, and the plans to implement, in-house, the long lead time tests. The available optical and mechanical properties will be considered first, followed by a discussion of the thermal problems including window surface temperature response, heat leaks, and contamination control afforded by heating the window.

19. (Continued)

Optical and Mechanical - The optical properties (emittance and transmissivity) of two of the most promising candidate materials, sapphire and IRTRAN 4 (polycrystalline zinc selenide), are shown in figures 1 and 2, respectively. The sapphire response cuts off at approximately 6μ. However, the IR instrument requirements are achieved by the use of IRTRAN 4 which has a capability to 16μ.

The appropriate structural thickness, t, for each material was calculated from the following equation

$$t = C_1 \frac{Pr^2}{s}$$

where

P = pressure
r = radius of window
s = modulus of rupture
C_1 = factor of safety

For a one inch diameter window and a factor of safety of four, the corresponding window thicknesses are 0.2 in. for sapphire and 0.4 in. for IRTRAN 4. These values correspond closely to those provided by all of the contractors in their proposals. Preliminary structural tests at partial simulation of the Venus descent full pressure 100 atm.) and room temperatures inditated satisfactory sapphire performance. The failure of the window assembly at higher temperatures (450°K) was due to the buckling of the thin metallic backup tube as opposed to the window failure. On the basis of the available evidence it is concluded at this time that there are no structural or optical problems anticipated for the windows currently baselined for the probes.

Additional information on the physical and optical properties of interest is available in references 1, 2, and 3.

Thermal - The thermal problems of heat leaks* by penetrations in the insulation required for instrument windows as well as the surface temperature control to insure no contamination by condensibles, have been recognized and considered to be of prime importance by all the proposers to the Pioneer Venus RFP. However, neither the depth nor state of the treatment of these items were sufficiently detailed to provide the definitive answers required. Accordingly, a two pronged program involving both analytical calculations and experimental verification tests has been initiated by the Pioneer Venus Project to study these problems in depth. The physical model of the window assembly chosen for the initial analysis, which is shown in figure 3 is representative of those proposed for study in the Phase B effort.

---

* Contractor calculations show 15% of the total heat soaked to the probe interior is due to penetrations of which 1/2 is attributable to windows.

19. (Continued)

A multi-node detailed thermal model (see figure 4), incorporating all the pertinent physics including forced conviction, radiation exchange, conduction, thermal capacitance, and heat sources has been set up and programmed for machine computation by J. Kirkpatrick. The purpose of these calculations is to parametrically investigate the influence of window configuration, initial temperature, and power addition (heating) on the window thermal response. The initial results are shown in figure 5 wherein, the window temperature is compared to the ambient atmospheric temperature for various values of heating (0, 3 and 5 watts). Note, in particular, the initial favorable temperature difference attributable to the pre-conditioning of the vehicle by the high speed re-entry. Also at lower altitudes the considerable thermal lag of the window relative to the atmosphere. In the case of the thin descent capsule skin of titanium, which is backed up by an efficient low density insulator the temperature difference is much less. The addition of 3 watts to the window maintains its temperature above ambient until 75 minutes (36 km) and for 5 watts the crossover is delayed to 87 minutes (27 km). One of the critical factors identified in this parametric study was the important heat transfer contribution of the supporting metal tube.

The adequacy of the thermal model described above and assessment of the component design suitability will be evaluated in tests to be performed in the Ames facilities:

(1) An existing 3 foot diameter shroud capable of operational temperatures to 400°K at a pressure of 1 ATM.

(2) A smaller scale (8" dia. cylinder 15" in length) test apparatus now being fabricated which will have the capability of testing components at maximum conditions of 800°K and 100 ATM pressure.

These tests will be complementary to those proposed and to be performed by the contractors.

A mock-up of the window assembly to be used in the Ames tests shall be constructed by EIMAC using the existing high temperature brazing procedures for joining sapphire to kovar.

REFERENCES:

(1) "Union Carbide Corporation - Crystal Products Department Bulletin"

(2) "Kodak IRTRAN Infrared Optical Materials Kodak Publication U-TE"

(3) "Transmittance of Optical Materials at High Temperature in the 1-micron to 12 Micron Range" Gillespie, Olsen, Nicholas, Applied Optics, Vol. 4, No. 11 (Nov. 1963), p. 1488.

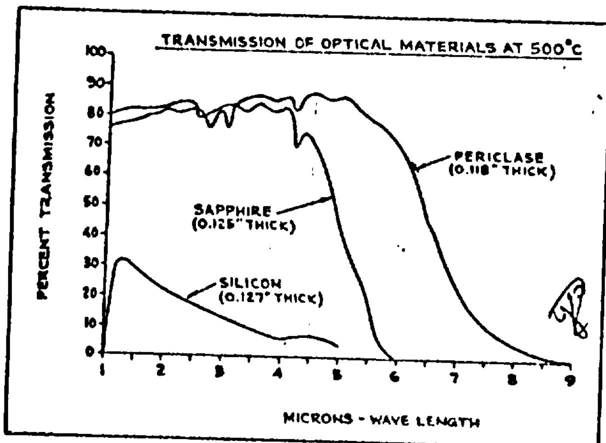


Fig. 9 – High Temperature Transmission

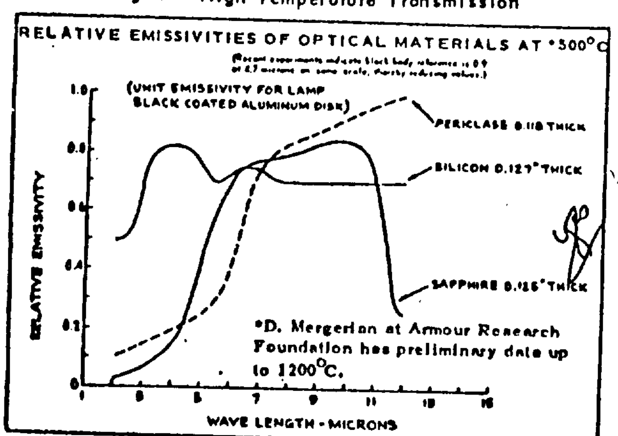
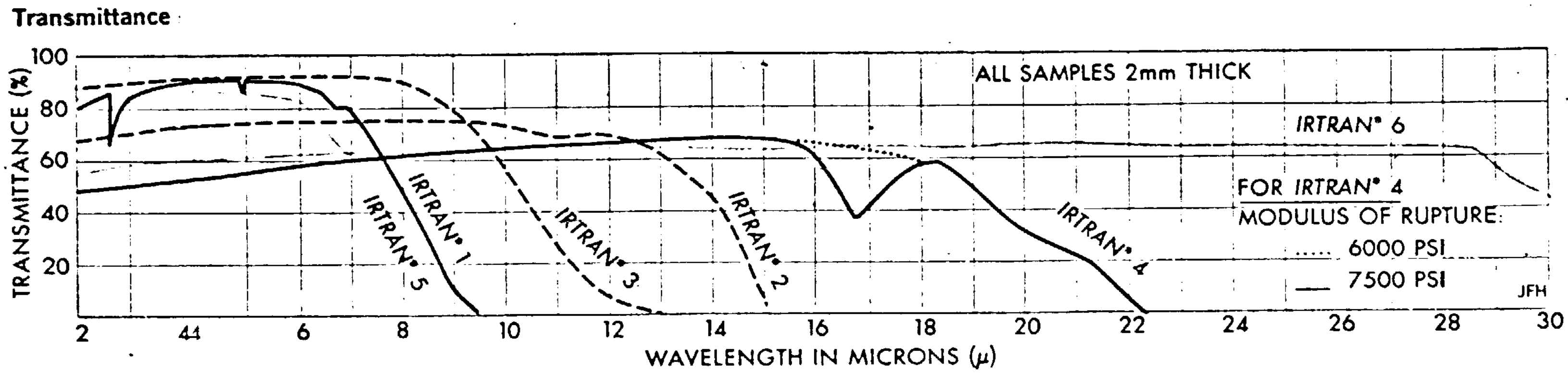


FIG. 10 – Relative Emissivity

FIGURE 1. OPTICAL PROPERTIES OF SAPPHIRE



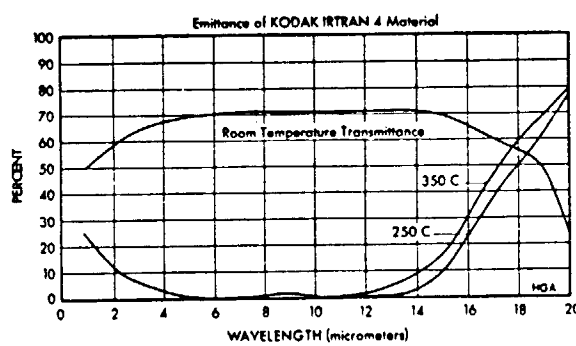


FIGURE 2: OPTICAL PROPERTIES OF IRTRAN 4

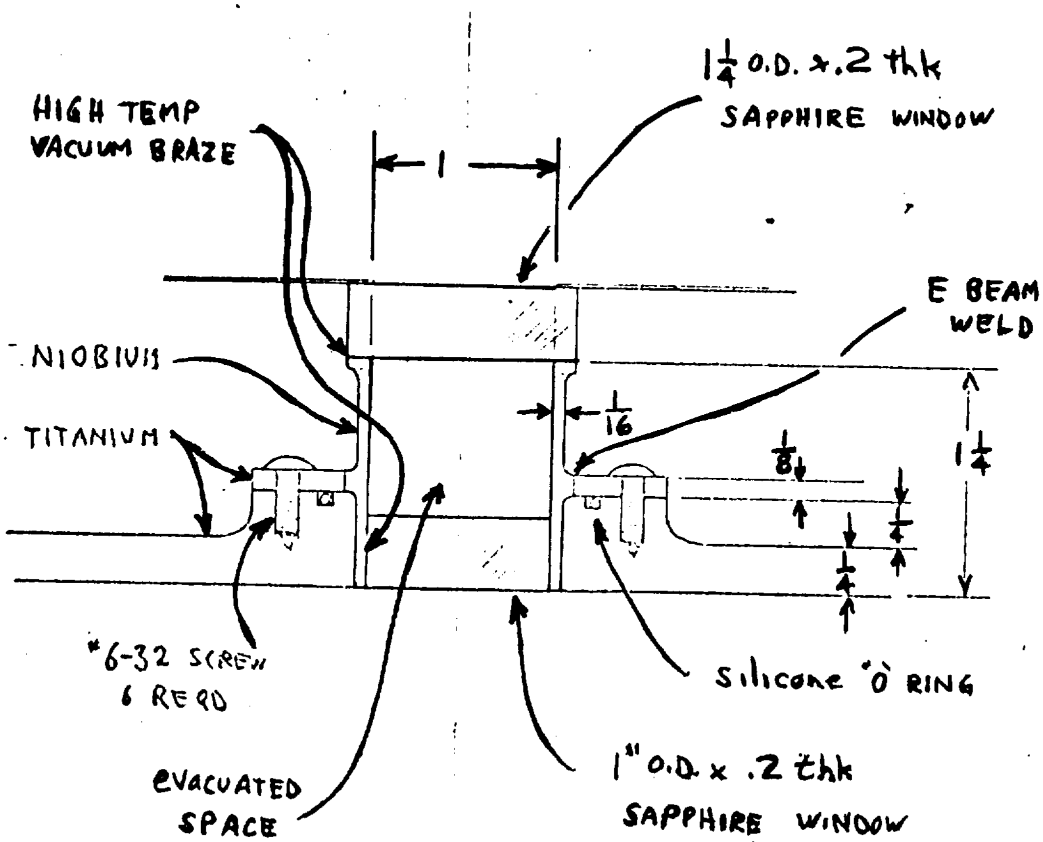
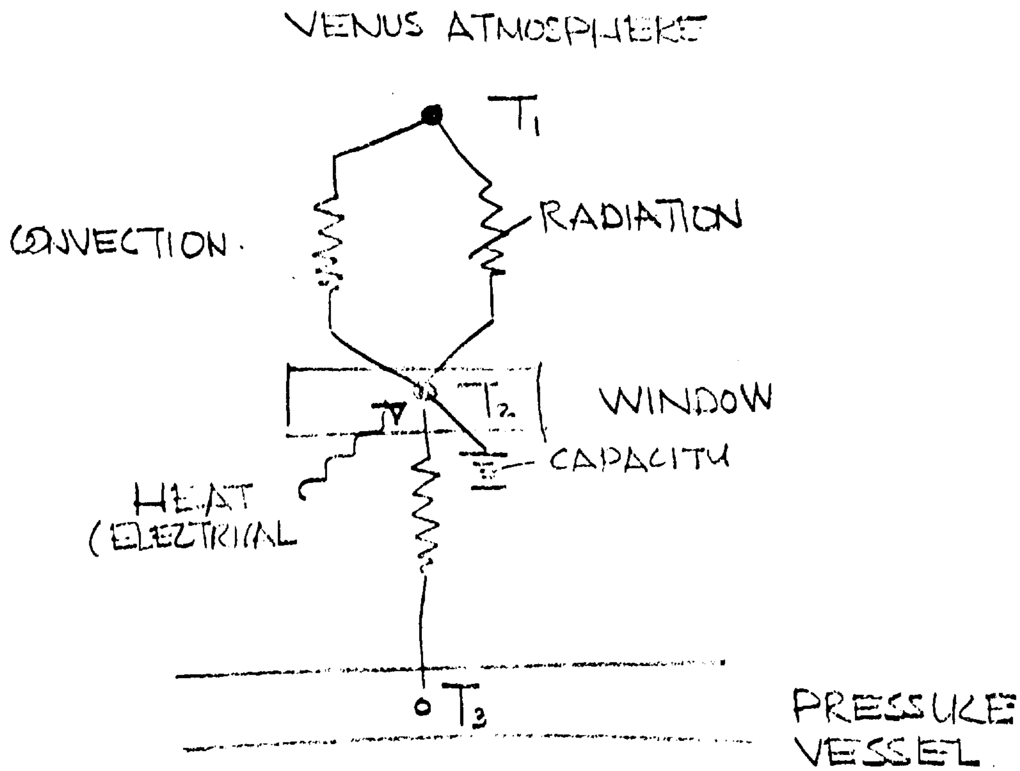


FIG 3. TYPICAL WINDOW CONSTRUCTION

1. MODEL

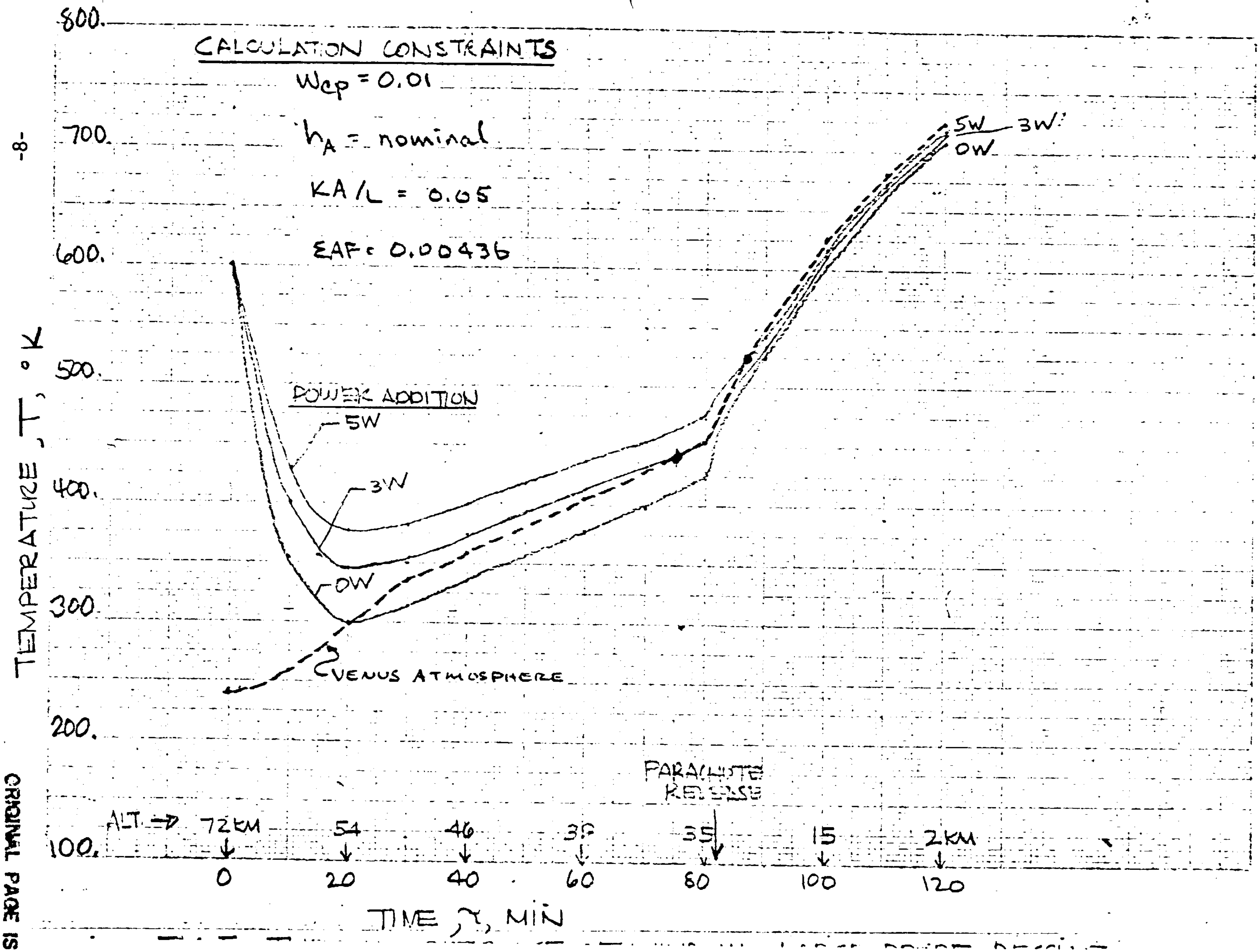


2. GOVERNING EQUATION

$$Q_{IN} = Q_{OUT} + Q_{STORAGE}$$

$$Q_{ELECTRICAL} + hA(T_1-T_2)+\epsilon AF\sigma(T_1^4-T_2^4) = \frac{KA}{L}(T_2-T_3)+WC_p\frac{dT_2}{d\theta}$$

FIG. 4 ANALYSIS MODEL AND GOVERNING EQUATION


CALCULATION CONSTRAINTS
$W_{cp} = 0.01$
h_A = nominal
KA/L = 0.05
EAF = 0.00436
POWER ADDITION
5W
3W
0W
VENUS ATMOSPHERE
PARACHUTE RELEASE
5W
3W
0W
ALT →
72KM
54
46
38
35
15
2KM
0
20
40
60
80
100
120
TIME, τ, MIN
TEMPERATURE, T, °K
800.
700.
600.
500.
400.
300.
200.
100.

20. Report on status of reflecting heat shield technology (Generated 6-5-72)

RESPONSE: (6-5-72)

A status report was presented by P. Nachtsheim of NASA/ARC's Thermal Protection Branch. Copies of supporting reports are attached.

In response to a specific question of what weight would be saved on the miniprobes if reflecting rather than conventional heat shields were used the following information was provided.

The minimization of heat shielding weight (existing nominal design = 8.5 lb or w/w Total = 0.17) is of critical importance for the mini-probe because the nominal scientific payload of 3 lb represents an extremely small fraction (0.06) of the probe entry weight.

Initial ARC calculations show that a weight saving of 1/2 to 1 lb could be realized. This could be increased to 2-1/2 lb by going to a more efficient material such as one of the dielectrics which has a higher sublimation energy than Teflon.

The contractors during the course of the Phase B study (as specified in the RFP Statement of Work) will investigate, in greater detail, the possible potential afforded by the use of the reflecting heat shield concepts (i.e., Teflon) currently being developed and examined at ARC.

Tests in the Ames facility (AEHS) shall be conducted during the Phase B study at heating conditions simulating those expected during Venus entry to provide a common evaluation of candidate materials, and more importantly, to corroborate the validity of the design.

AMERICAN ASTRONAUTICAL SOCIETY

the 17th ANNUAL MEETING

THE OUTER SOLAR SYSTEM

PREPRINT NO. AAS-71-147

REFLECTING ABLATIVE HEAT SHIELDS FOR RADIATIVE ENVIRONMENTS

Philip R. Nachtsheim

David L. Peterson

John T. Howe

June 28-30, 1971

Washington Plaza Hotel
Seattle, Washington

AIAA Paper No. 72-89

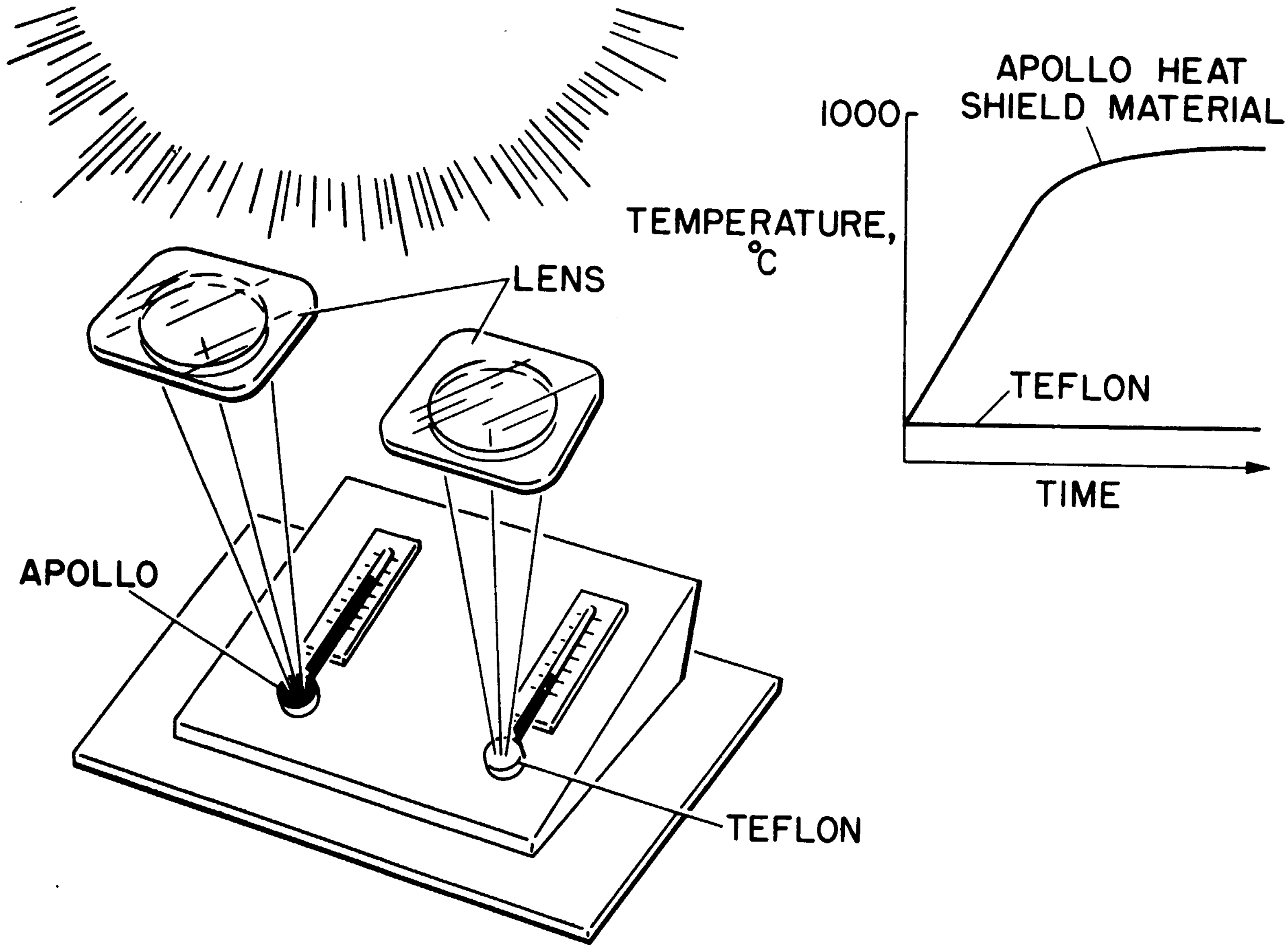
REFLECTING ABLATING HEAT SHIELDS FOR PLANETARY ENTRY

by
DAVID L. PETERSON, PHILIP R. NACHTSHEIM
and
JOHN T. HOWE
NASA Ames Research Center
Moffett Field, California

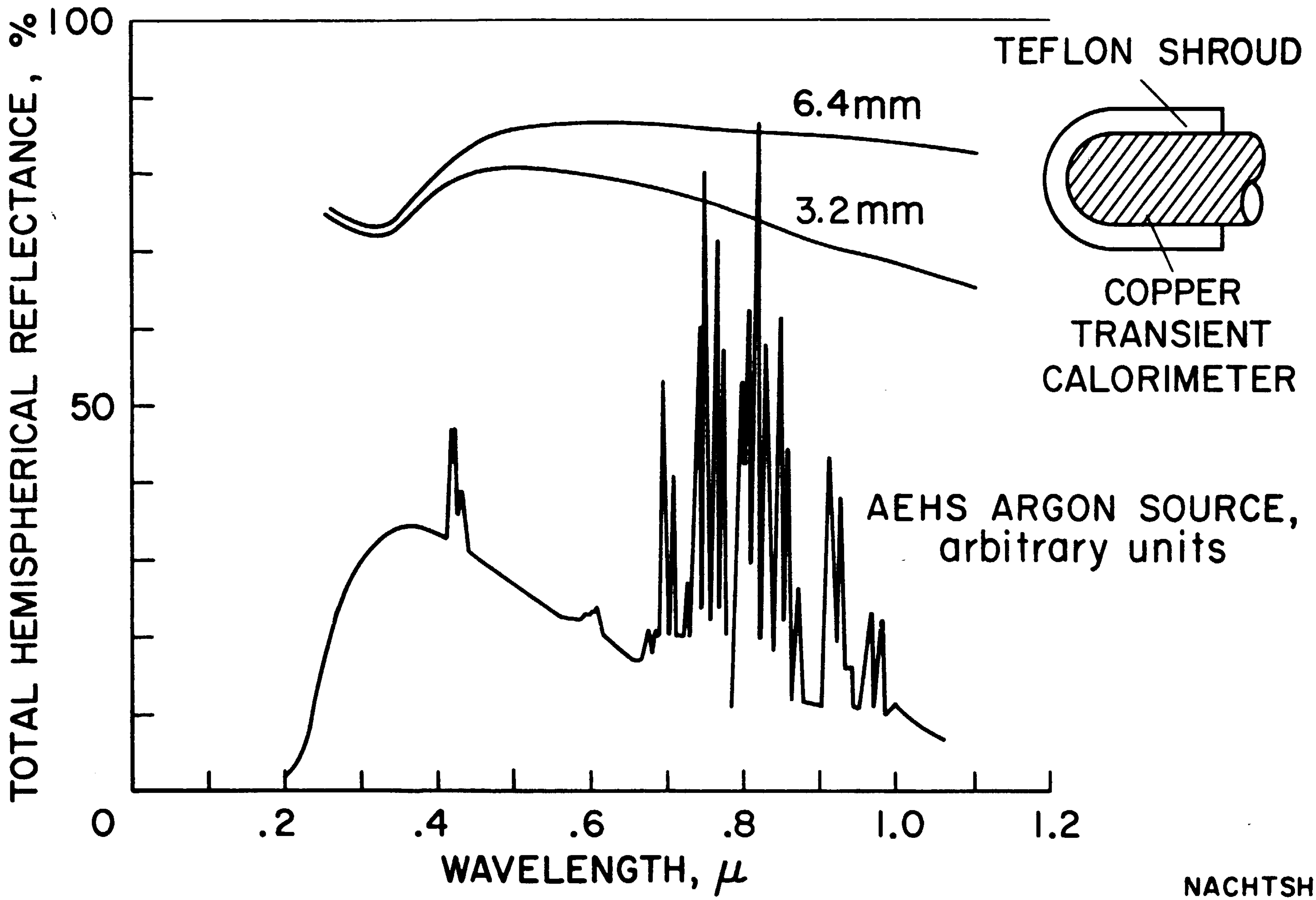
AIAA 10th Aerospace Sciences Meeting

SAN DIEGO, CALIFORNIA/JANUARY 17-19, 1972

PRINCIPLE OF REFLECTING HEAT SHIELD

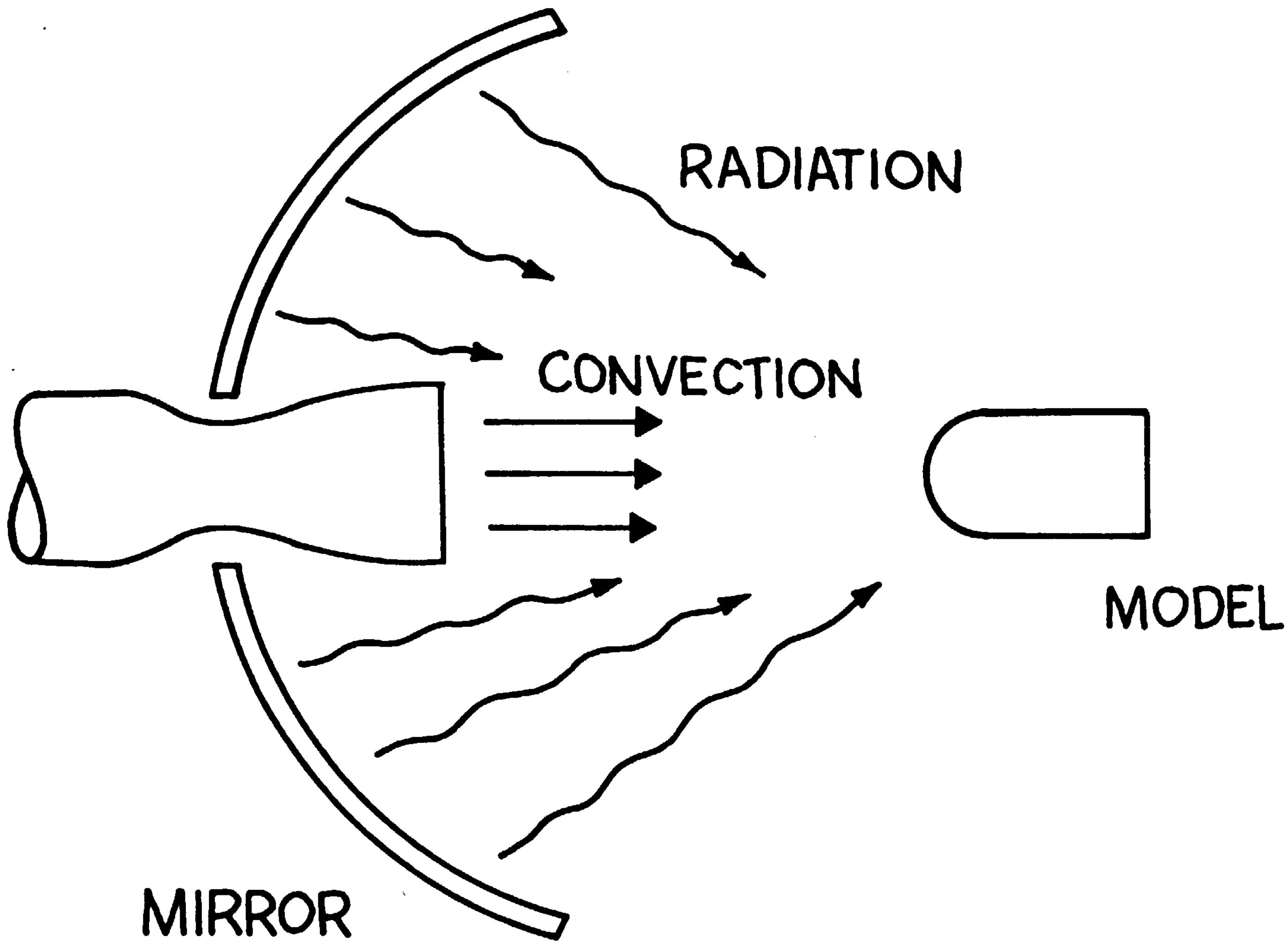


SPECTRAL REFLEC ANCE FOR TEFLON



NACHTSHE

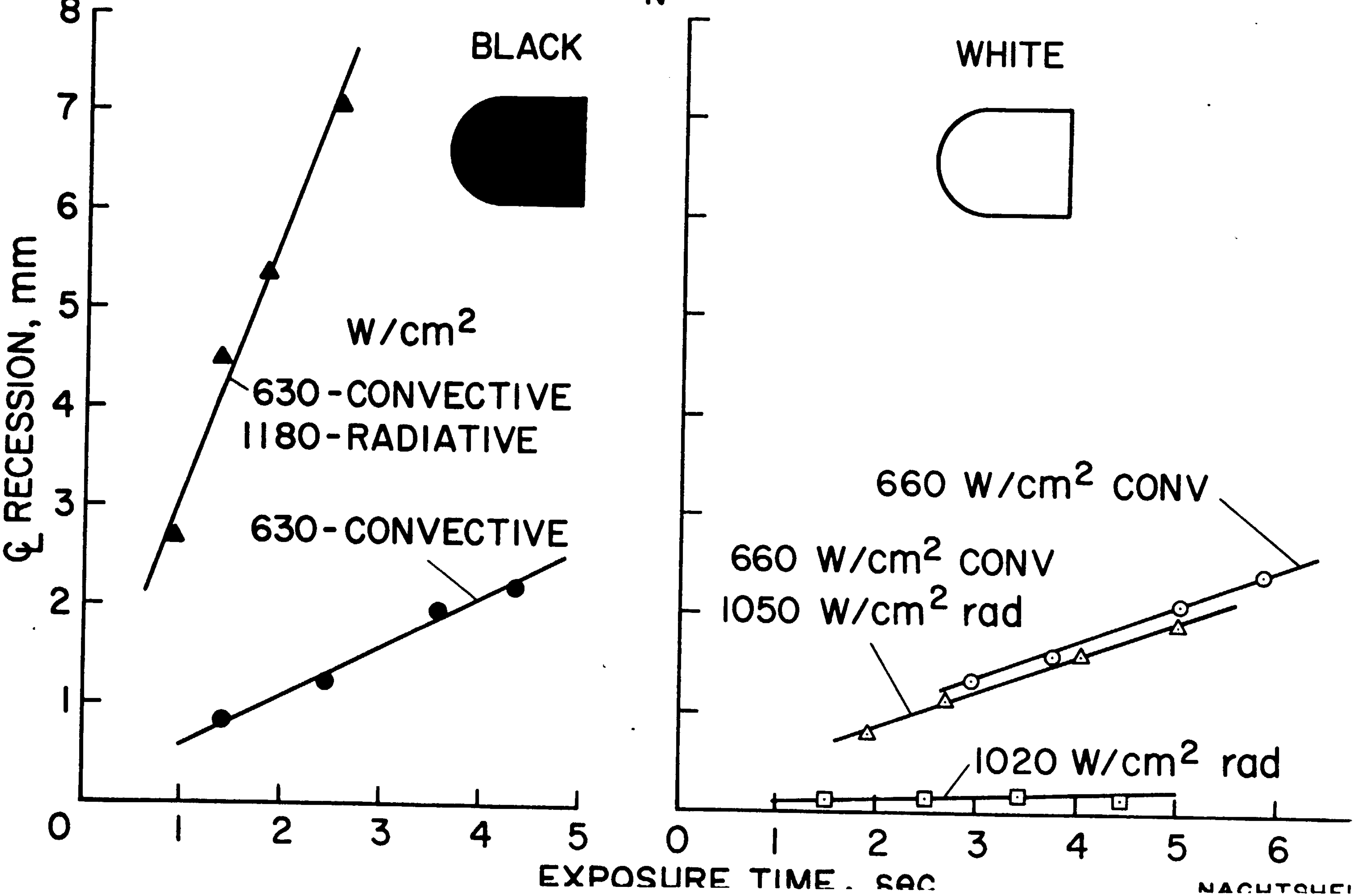
SCHEMATIC OF COMBINED HEATING FACILITY



3

COMPARISON OF WHITE AND BLACK TEFLON UNDER CONVECTIVE AND RADIATIVE HEATING CONDITIONS

$R_N = 7.6$ mm



NACHTSHEI

ADVANTAGES OF A REFLECTING TEFLON HEAT SHIELD

1. GREATER FUTURE POTENTIAL
   - EXTRA SCIENCE PAYLOAD FOR MORE SEVERE 1980 MISSION
   - TRANSFER OF TECHNOLOGY TO JUPITER ENTRY

2. GREATER RELIABILITY
   - FLIGHT EXPERIENCE: HIGH SHEAR AND TURBULENT HEATING
   - RADIATION OVERSHOOT CAPABILITY
   - FLIGHT QUALIFICATION WITHIN PRESENT FACILITY CAPABILITY

3. LOWER COST
   - VERIFICATION OF HEAT SHIELD DESIGN
   - MANUFACTURE

4. LIGHTER WEIGHT POSSIBLE: BLUNTER SHAPE
   - LESS CONVECTIVE HEATING

     LAMINAR

     TURBULENT
   - MORE RADIATION: REFLECTION WITHOUT APPRECIABLE ABSORBTION
   - LESS HEATING (TOTAL)

SUMMARY

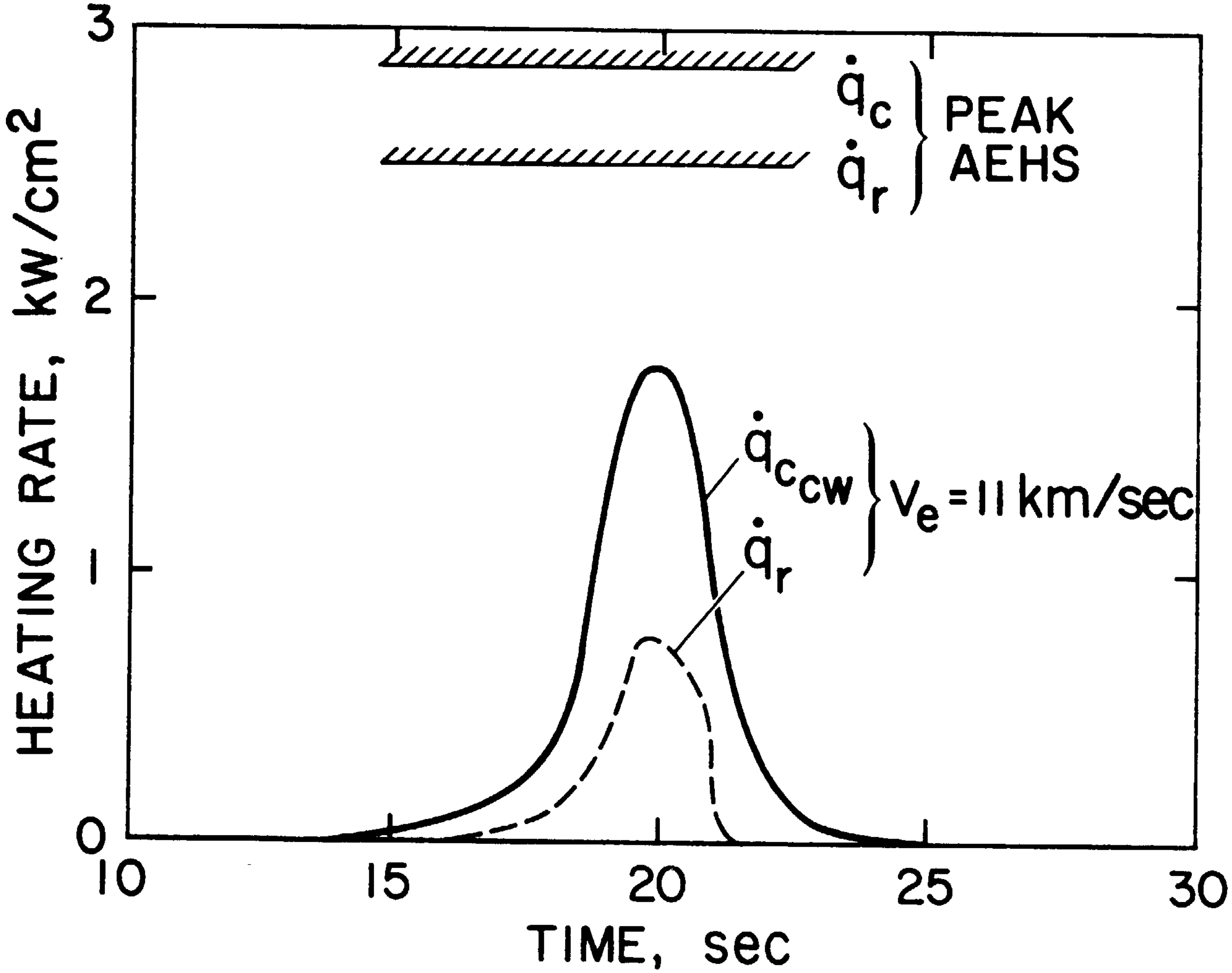
1. TEFLON HEAT SHIELD WEIGHT COMPETITIVE FOR CONICAL SHAPES

2. LIGHTER WEIGHT POSSIBLE FOR BLUNT SHAPES

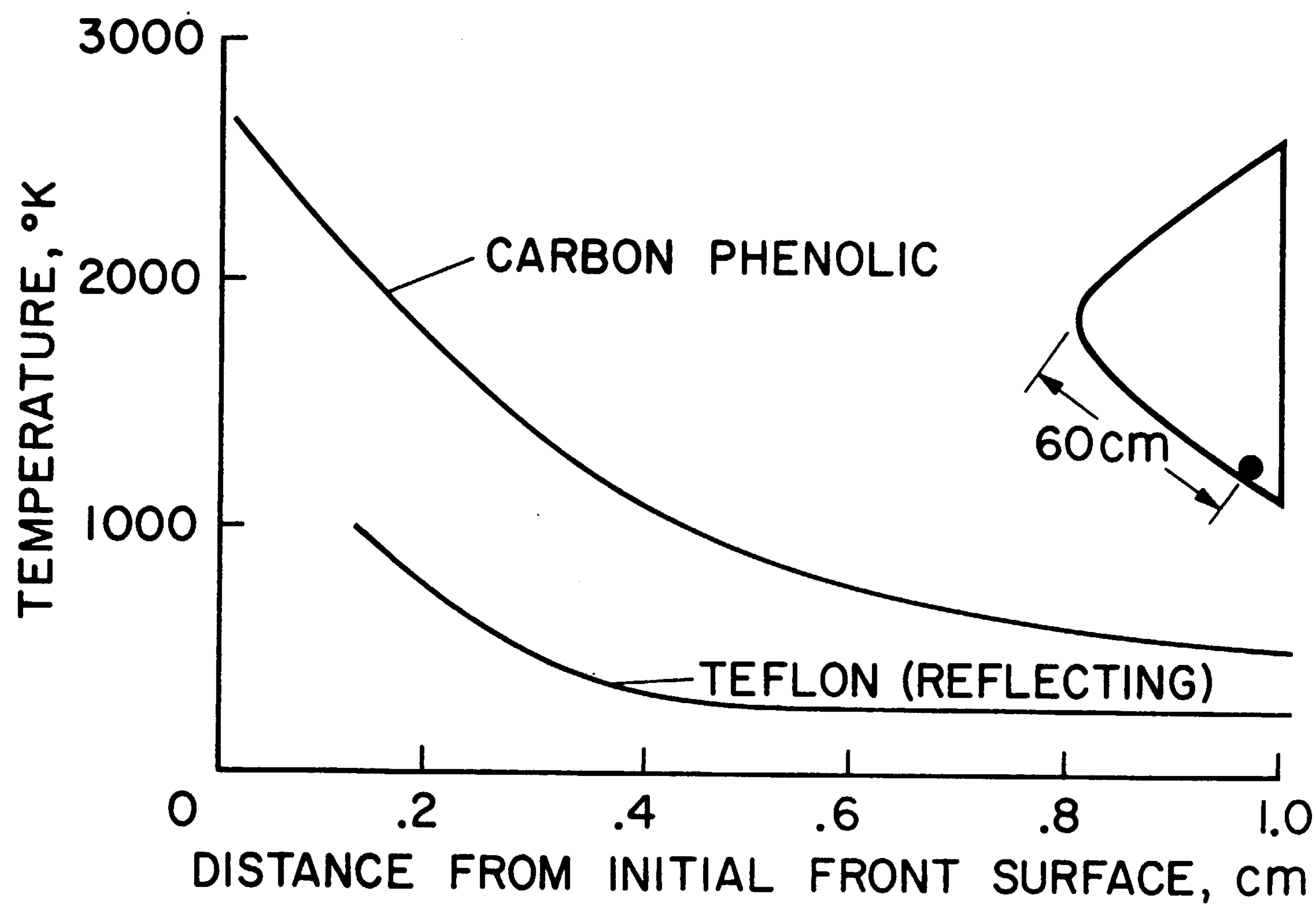
3. EVALUATIONS WILL BE PERFORMED AT AMES
   - CONTRACTOR'S MATERIALS
   - TEFLON

COMPARISON OF TYPICAL VENUS ENTRIES WITH AEHS PEAK PERFORMANCE

1.27 cm DIAMETER MODEL



MAXIMUM TEMPERATURES DURING INTERVAL FROM PEAK HEATING TO PARACHUTE DEPLOYMENT VENUS ENTRY — PHASE A TRAJECTORY — MAIN PROBE



REFLECTIVE MATERIALS RESEARCH

EXPERIMENTAL ENVIRONMENT

COMBINED CONVECTIVE-RADIATIVE HEATING

FACILITY:	ADVANCED ENTRY HEATING SIMULATOR
RADIATIVE:	2.5 kW/cm^2 max
CONVECTIVE:	3.0 kW/cm^2 max
PRESSURE:	3.0 atm stag max
MODEL SIZE:	1.5 cm dia (AVERAGE)
GASES:	AIR; CO_2/N_2 (VENUS)

21. The Pioneer Venus Project Office is to generate a report on the 1978 Orbiter Targeting Considerations.
(Generated 4-24-72)

RESPONSE: 6-5-72 by R. Jackson

A report entitled "1978 Orbiter Targeting Considerations" was distributed to the SSG members.

1978 Orbiter Targeting Considerations

1. Targeting Questions
2. Periapsis Altitude
3. Orbit Period/Apoapsis Altitude
4. Periapsis Latitude/Orbit Inclination
5. Type I versus Type II Trajectories to Venus

1. Targeting Questions

The 1978 Venus Orbiter targeting questions which are influenced by science requirements are: periapsis altitude range, apoapsis altitude/period, periapsis latitude/orbit inclination, and Type I versus Type II trajectories to Venus.

The following sections attempt to explain the limits which apply to each of the targeting questions.

2. Periapsis Altitude

Periapsis altitude is the smallest distance from the solid surface during each orbit.

The minimum periapsis altitude is set by the amount of air friction heating which the spacecraft can tolerate. The minimum altitude is around 150 km when calculated with the GSFC 3609 atmosphere. An orbit minimum altitude somewhat higher will allow the mission to be unaffected by atmosphere uncertainties and orbit prediction uncertainties; 200 km is suggested as a comfortable number.

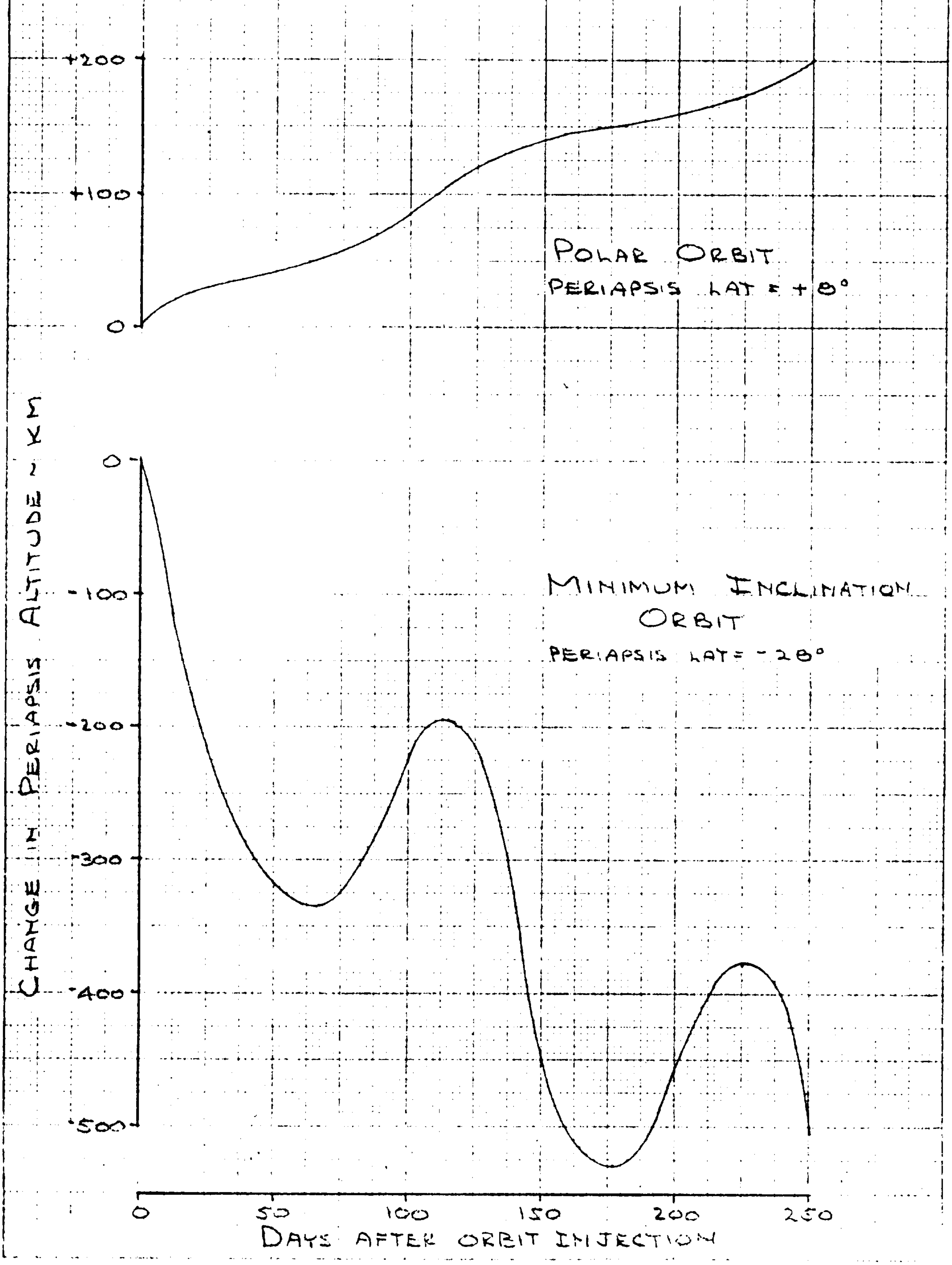
The orbit periapsis altitude will change throughout the mission as the orbit responds to third-body perturbations from the Sun. For a polar orbit, the altitude will gradually increase. For a low inclination orbit, the altitude will initially decrease and then increase. Figure A shows sketches of the periapsis altitude history.

The periapsis altitude can be controlled to remain within a small range by periodically firing the spacecraft thrusters at apoapsis. A periapsis altitude range of ±100 km from nominal is a comfortable number.

The target periapsis for orbit insertion must be chosen high to allow for aim point uncertainties. After several days in orbit, periapsis will be lowered by firing spacecraft thrusters at apoapsis. The nominal target periapsis will be around 400 km.

FIGURE A PERIAPSIS HISTORY

24 HOUR ORBIT PERIOD



3. Orbit Period/Apoapsis Altitude

Once periapsis is chosen, the orbit period and apoapsis altitude are related as shown in figure B.

The orbit period is selected by controlling the amount of propellant expended by the orbit insertion motor. Shorter periods require more propellant and longer periods require less propellant.

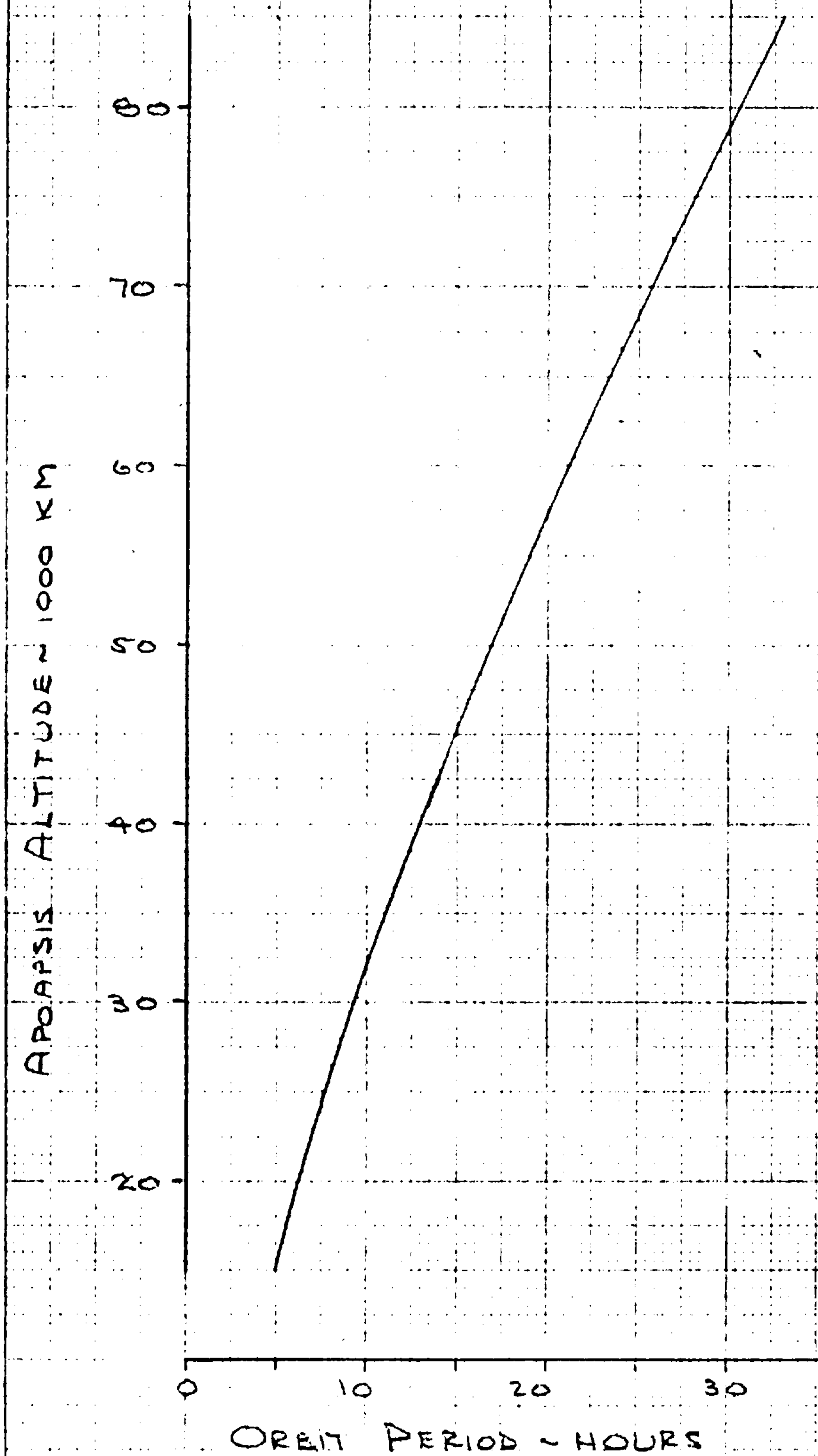
Science instrument weight and propellant weight are interchangeable as far as the spacecraft knows, so greater instrument weight can be put into a long period orbit than into a short period orbit. The weight-period relationship is shown in figure C.

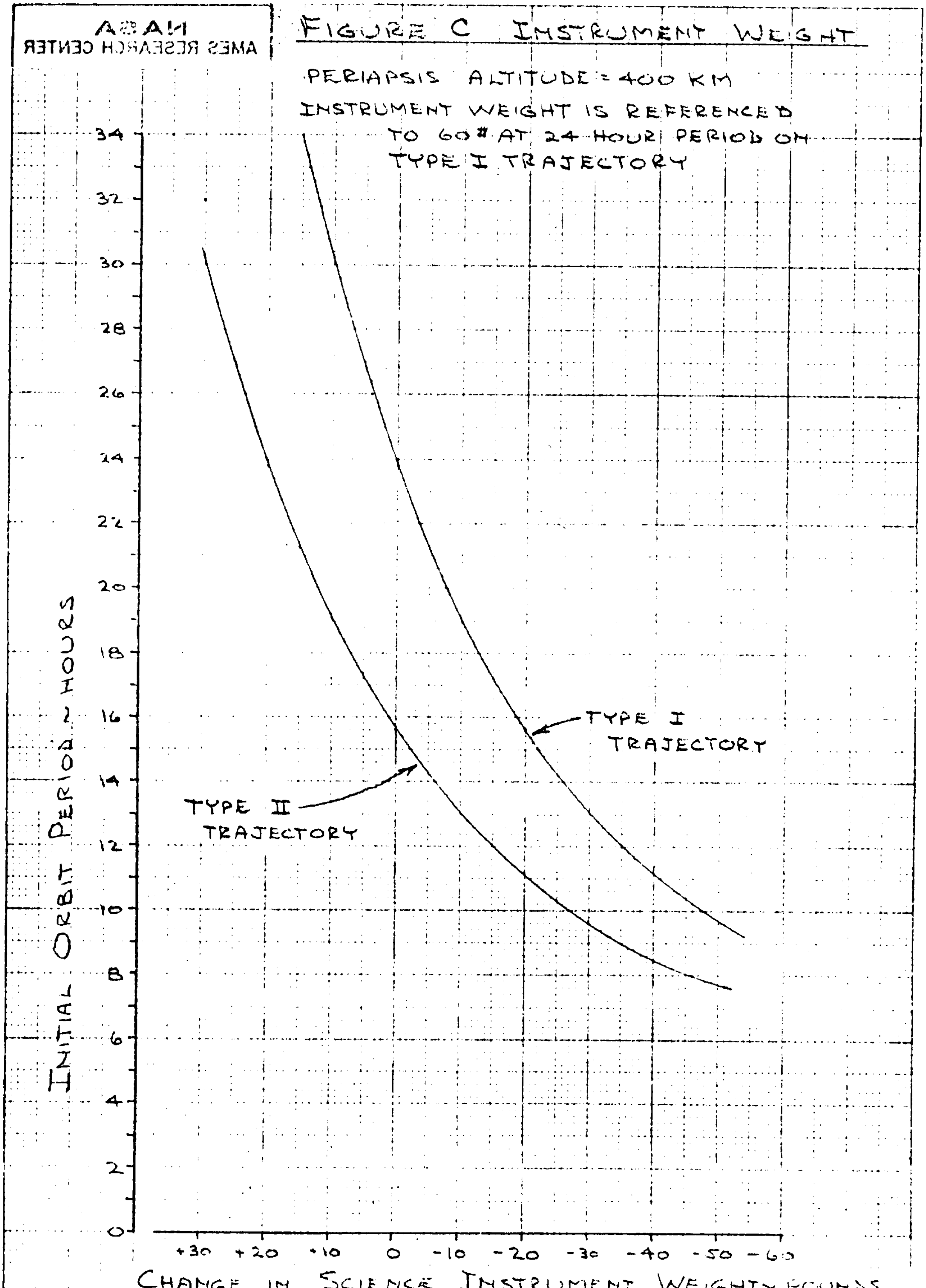
The orbit period will not be changed by third-body perturbations from the Sun. The apoapsis altitude will change by about the same distance as the periapsis altitude.

FIGURE B APOAPSIS - PERIODS

PERIAPSIS ALTITUDE = 400 KM

SURFACE RADIUS = 6050 KM





NASA
AMES RESEARCH CENTER
FIGURE C INSTRUMENT WEIGHT
PERIAPSIS ALTITUDE = 400 KM
INSTRUMENT WEIGHT IS REFERENCED TO 60# AT 24 HOUR PERIOD ON TYPE I TRAJECTORY
TYPE I TRAJECTORY
TYPE II TRAJECTORY
INITIAL ORBIT PERIOD ~ HOURS
CHANGE IN SCIENCE INSTRUMENT WEIGHT ~ POUNDS
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
+30
+20
+10
0
-10
-20
-30
-40
-50
-60

4. Periapsis Latitude/Orbit Inclination

Periapsis latitude and orbit inclination are related to the declination of the approach trajectory asymptote and the target point of the approach trajectory.

Figure D shows the locus of periapsis latitudes which may be used with a Type I trajectory to Venus. The orbit inclination is shown for selected points along the locus.

Figure E shows similar information for a Type II trajectory to Venus.

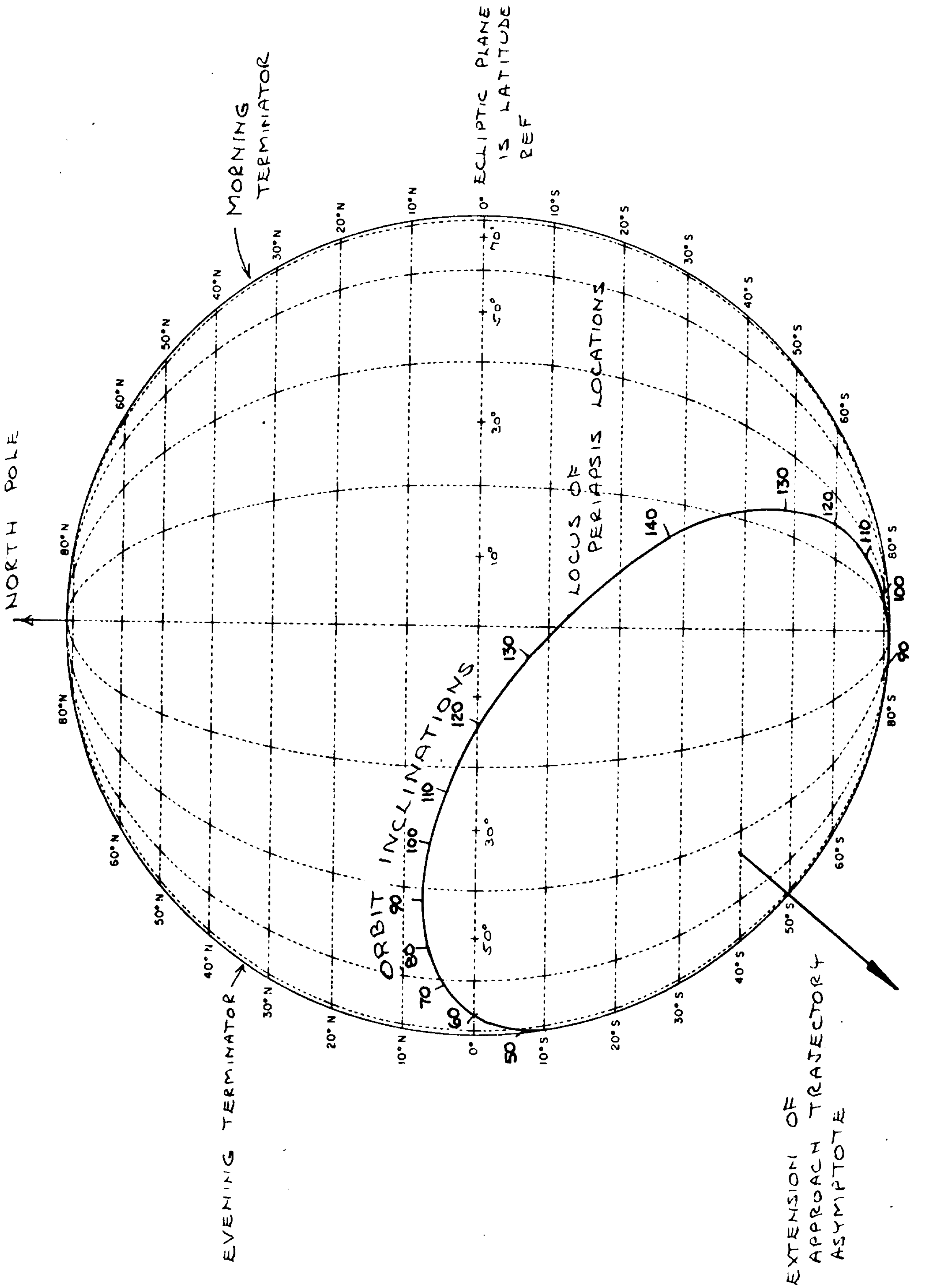
Periapsis latitude and orbit inclination will be changed only a few degrees by third-body perturbations from the Sun.

Periapsis will move toward the evening terminator at the rate of 1.6 degrees per day. The number of days with daylight periapsis passages may be estimated from figures D and E from the longitude difference between periapsis and the evening terminator.

When periapsis is near the ecliptic (latitudes near zero), both the periapsis and apoapsis parts of the orbit will pass through Venus' shadow (eclipse) during some part of the mission. Apoapsis eclipses are long because the spacecraft is moving slowly, and place a severe requirement on the spacecraft power and thermal control systems. Eclipse durations will be manageable if periapsis latitude is greater than ±20°.

FIGURE D PERIAPSIS LOCATIONS

1978 TYPE I TRAJECTORY TO VENUS

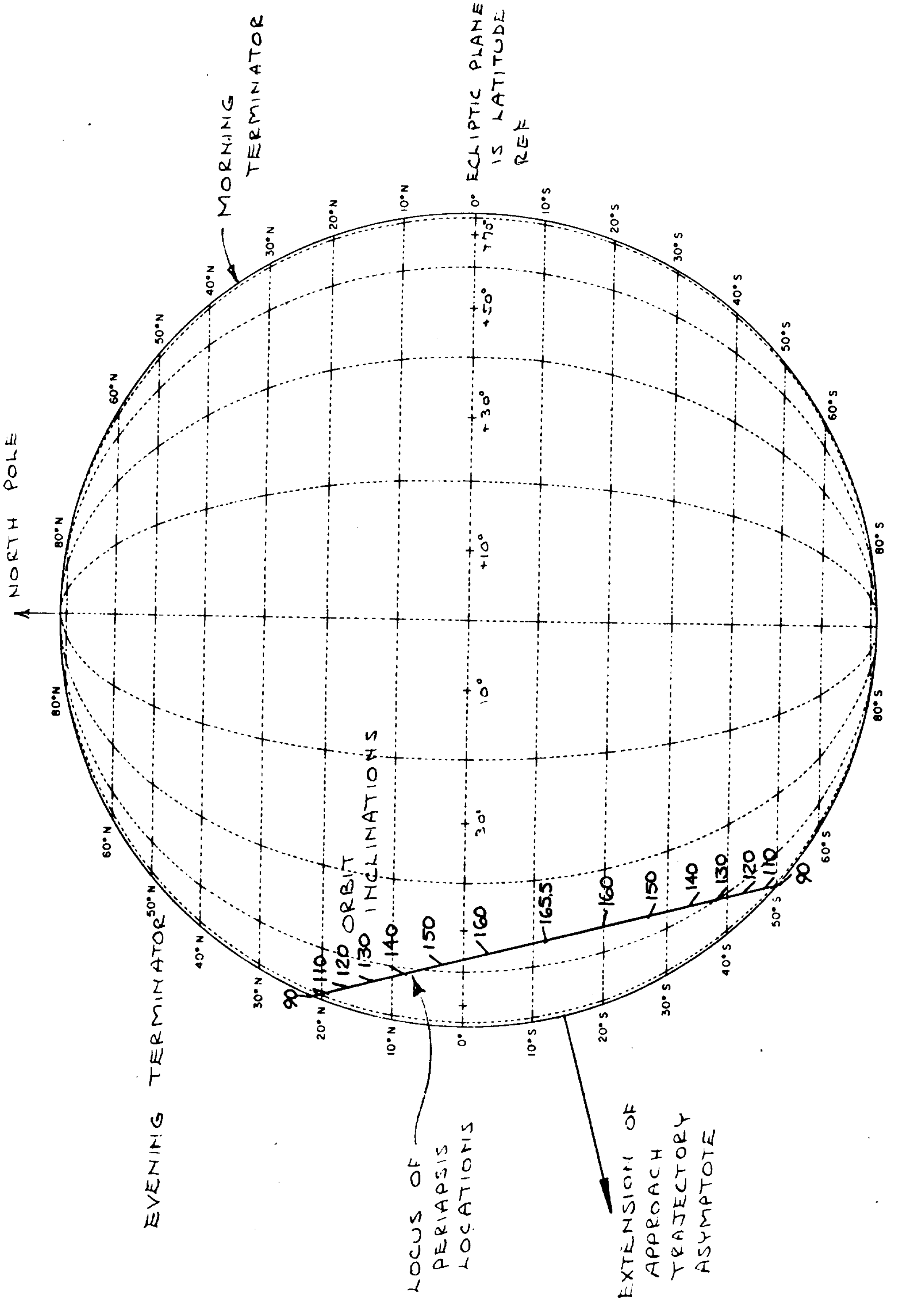


VIEW OF SUNLIT HEMISPHERE OF VENUS AT SPACECRAFT ARRIVAL

SUB-SOLAR LONGITUDE IS CENTRAL MERIDIAN

FIGURE E PERIAPSIS LOCATIONS

1978 TYPE II TRAJECTORY TO VENUS



VIEW OF SUNLIT HEMISPHERE OF VENUS AT SPACECRAFT ARRIVAL

SUB SOLAR LONGITUDE IS CENTRAL MERIDIAN

5. Type I vs. Type II Trajectories to Venus

Two different types of interplanetary trajectories are available for use between Earth and Venus.

One, called Type I, is a direct trip lasting about 120 days, where the spacecraft arrives at Venus before passing perihelion. Type I launch dates are in August 1978, and Venus arrival dates are in December 1978.

The second, called Type II, is a longer trip lasting about 200 days, where the spacecraft passes perihelion before arriving at Venus. Type II launch dates are in May 1978 and Venus arrival dates are in December 1978.

Type II trajectories require lower launch weights than Type I, but produce greater weight-in-orbit because of substantially lower Venus arrival velocities.

The two disadvantages of Type II trajectories are: the 80-day longer trip time to Venus and consequent longer storage time for the orbit insertion rocket, and the higher design heat input which results when the spacecraft passes perihelion on the way to Venus.

The arrival geometry at Venus is different, as is shown in figures D and E.

22. The Pioneer Venus Project is to provide an evaluation of the USSR versus USA space instrumentation capabilities as related to Venus exploration.
(Generated 3-29-72)

RESPONSE: 4-24-72

A library of Russian Space Exploration has been started in order to establish a detailed history of the Venera flights. Numerous papers have been collected pertaining to the Venera 4 through Venera 7 missions. Little is known, so far, about Venera 8, except for a statement by G. I. Petrov, Director of the Soviet Institute of Space Research, who said that in addition to measurements previously made, "a few additional experiments," will be made, whose main objectives are to analyze the Venusian soil so that it can be compared with Earth soil. He said the analysis will involve bombarding the surface with radiations that can be sensed by spacecraft systems, and the resultant reaction will indicate the basic elements of the soil.

An attempt was made to launch Venera 9 (Cosmos 482) on March 27, 1972, but it failed to leave Earth orbit.

A valuable addition to any student of the Russian Space Program is the recently written Soviet Space Programs, 1966-70, Staff Report, Senate Document No. 92-51, for use of the Committee on Aeronautical and Space Sciences, United States Senate, by the Library of Congress.

An assessment of the recent Soviet Mars Missions and their relation to the U. S. Planetary Program is given in the JPL internal Report No. 201-72-1, "Considerations of the Soviet Planetary Program in Light of the Mars-2 and Mars-3 Missions," 22 February 1972.

Conversations with the JPL people indicate that they are now studying the Venera program in order to make a similar assessment as was made for the Mars missions.

Study of the Russian Space Program will be a continuing effort in order to compare their program with ours.

During the meeting, Dr. Blamont provided an ESRO literature recon on Venera for use by the Pioneer Venus Project.

RESPONSE: 6-5-72

A study of USSR space exploration has been continuing.
A bibliography of Russian Scientists who have been affiliated with the Venera program is being compiled and will be available in the project office. Instruments that have been identified in with the Venera experiments are also being catalogued.

22. (Continued)

A quote from Soviet Aerospace, May 22, 1972, referring to the Cospar meeting in Madrid, Spain, is of interest:

> "The latest meeting involved the proposals for complementary activities during planetary explorations and recommendations for the exchange of planetary experiment information. The meeting was held in conjunction with the outer planetary meeting of Cospar. Leader of the USSR group is G. I. Petrov, Director of the Science Instituted Space Research. John E. Naugle, Associated Administrator for Space Science, NASA, heads the U. S. Group."

One of the participants of that meeting was Dr. I. Rasool.

23. Conduct further analysis on the operation of the "Kyle Boiler" and determine the applicability of it for Venus atmosphere measurements.
(Generated 3-29-72)

RESPONSE: 4-24-72

Dr. Gille reported that the instrument as presently designed measures the temperature rise of a gas flowing through a heated tube (0.5 cm X 0.5 cm cross section). The instrument measures the product of the latent heat of the condensibles in the gas and the mass flow of the gas. One of the major problems with this instrument is the amount of power required for heating the tube. It is estimated that on Venus approximately 1 watt would be required in the upper atmosphere while 30 watts would be required in the lower atmosphere. Another problem is the definite possibility of ambiguous interpretation of data received.

Following a discussion, it was decided that no further investigation of the use of this instrument is desirable.

This action item is therefore considered closed.

24. The Pioneer Venus Project is to identify critical scientific instruments and/or concepts which require "long lead development and/or study". Appropriate studies will be initiated. The Project will provide to the SSG continuing progress reports. (Generated 5-29-72)

A. Wind-Cloud-Altitude Radar.

RESPONSE: 4-24-72

Preliminary studies indicate feasibility of scaling down Apollo/ Surveyor type doppler radar, to fit large probe, and provide reasonably good performance in measuring probe velocity, distance to cloud layers, and probe altitude. (20 km max altitude, ± 10 cm/sec velocity accuracy, ± 100 meters altitude accuracy.)

In view of the large potential impact on probe design and program budget, a conceptual design/feasibility-verification study is needed prior to experiment selection.

An RFP for such a study has been prepared and procurement (open competition) is proceeding. Target dates:

RFP release	15 May 1972
Proposals due	5 June 1972
Contract Award	1 August 1972
First report	15 Sept. 1972

RESPONSE: 6-5-72

The RFP for a contractor study of feasibility was released to industry on May 25, 1972. Proposals are due back on June 15, contract award is anticipated by July 15 and first report by September 15.

Analysis to date and discussions with contractors indicate high confidence in 20 to 25 km operating altitude limit and 1-2% accuracies, with a 12-15 lb, 15-20 watt instrument compatible with the large probe. Better performance than this is not ruled out at this time.

24. (Cont'd)

B. Hygrometers

RESPONSE: 4-24-72

At least one existing type appears capable of operating in the Venus Atmosphere and providing unambiguous measurement of water vapor content, dew point, and stratification at a cost, weight and power low enough to warrant serious interest as a complement/backup for primary instruments. (i.e.: 100 grams, 10 milliwatts.)

A modest study and test effort is required to verify performance capability and possibly compare two or more candidate units.

An RFP for feasibility tests is in preparation . Target dates:

RFP release	1 June 1972
Proposals due	20 June 1972
Contract Award	1 August 1972
First Report	1 October 1972

RESPONSE: 6-5-72

Contract award is in process, to a contractor, for special environmental tests of a Brady Array Hygrometer, which appears to be a feasible candidate for the Venus Probe missions. The device will be modified to meet program requirements and subjected to a battery of tests to verify its ability to survive and operate in the chemical composition and the temperature and pressure of the Venus atmosphere. The entire test program will run for about 3 months but preliminary results should be available by mid July.

24. (Cont'd)

C. X-Ray Fluorescence Spectrometer

RESPONSE: 3-29-72

Distributed a report entitled, "X-Ray Fluorescence Analysis of Venus Atmospheric Dust," by M. Blanchard and G. Cunningham of NASA/ARC Planetology Branch.

RESPONSE: 4-24-72

A feasibility study is in progress at ARC. A preliminary report will be provided to the SSG by the June meeting.

RESPONSE: 6-5-72

No further information to report at this time. Dr. Hunten's memo of May 1972 effectively summarizes present status and important questions to be addressed before serious consideration can be given to either the alpha or gamma excitation devices. In addition, contacts have been made with Drs. Slanger and Young relative to their work on UV fluorescence instruments.

A report entitled, "Nuclear Fluorescence Experiments, a Tentative Evaluation," by D. M. Hunten was distributed to the SSG members.

X-RAY FLUORESCENCE ANALYSIS OF VENUS ATMOSPHERIC DUST

PRINCIPAL INVESTIGATOR: MAXWELL B. BLANCHARD

COINVESTIGATOR: GARY CUNNINGHAM

PLANETOLOGY BRANCH

SPACE SCIENCE DIVISION

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MOFFETT FIELD, CALIF. 94035

January 19, 1972

SUMMARY

The Venus aerosol X-ray fluorescence detector uses a radioactive source to excite characteristic X-rays in particles collected by impaction on the exterior of the entry probe. A thin Be window supported by a network of high-strength graphite fibers permits the exciting radiation to pass through the pressure shell and strike the sample and allows the characteristic X-rays to return and trigger the gas filled proportional detector. The gas filled detector is, itself, a very small pressure shell enclosing the window and is an integral part of the Venus probe's shell. Thus, in the unlikely event of a window rupture at the surface of Venus, the main interior of the probe will not be harmed. Sealed electrical connectors pass through the detector's pressure shell and transmit X-ray information as functions of number and energy. These data are sorted by energy in a pulse height analyzer and transmitted to earth for determination of chemical element content of the Venus cloud particles.

The simplicity, low power, light weight and small volume characteristics of this device permit its consideration as an inexpensive adjunt to other, more complex Venus atmosphere analyzers. Its insensitivity to wide ranging temperature changes and ruggedness permit its use at the probe's surface without danger of failure due to the hostile environment.

X-RAY FLUORESCENCE ANALYSIS OF VENUS ATMOSPHERIC DUST

INTRODUCTION

Determining the cloud particle composition in the Venus atmosphere is one of the major objectives of the Pioneer Venus experiment. It has been suggested that this composition can be deduced if only the compositions of the atmospheric gases are obtained. Although, theoretically, this may be so, in practice it is not. Our own upper atmosphere provides a good example of the complexity of a natural aerosol cloud in quasi equilibrium with its environment. This example emphasizes the difficulty of predicting the particulate component based only on knowledge of the gases present. In our stratosphere there exists a worldwide cloud of particles, usually between 10 and 30 km in height, with a complex layered structure concentrating at about 18 to 20 km altitude. Particles are slurry-like with solid materials encased in a liquid which is probably sulfuric acid. This acid is formed, possibly, by reactions between SO_2, H_2O and O_3 in the lower stratosphere. Some solid particles are crystals of ammonium sulfate and persulfate which likely are reaction products of the sulfuric acid drops with free ammonia. Others are insoluble rock-type particles with typical elements like Al, Si, Na, K, Cl, Ca, Ti and Cr. The gases, moisture and rock-like particles are probably injected to the stratosphere by volcanic eruptions, although energetic atmospheric disturbances such as major storms also may carry such materials aloft. Although the general composition and morphology of the particles is fairly similar worldwide, local differences can be immense. For example, the particulate can vary from a completely liquid droplet of H_2SO_4 to a completely dry crystal of $(NH_4)_2SO_4$ or a rock-like fragment. One major volcanic eruption, such as Agung in 1963, can completely change the nature of the local stratospheric aerosol and eventually the worldwide composition. Therefore, prediction of the aerosol component in the earth's atmosphere and on Venus by gas analysis alone is not possible. What is possible, however, is a direct measurement of the chemical elements in such atmospheric aerosols by X-ray fluorescence methods, using long-lived radioisotope sources to excite characteristic X-rays from the collected particulates.

X-RAY FLUORESCENCE METHOD

Characteristic X-rays are emitted from a sample whenever an incident energy source (electrons, X-rays or γ-rays) has kinetic energy greater than the binding energy holding the electrons in orbit (K, L, M, etc.) about the nucleus of each atom excited in that sample. The energy required to dislodge a K shell electron from Na (Z = 11) is 1.071 Kev and progresses upwards to 9.659 Kev for Zn (Z - 30). Nearly the same range also covers L shell electrons with 1.303 Kev required for Ca (Z = 31) progressing upwards to 21.766 Kev in U (Z = 92). Hence, simply speaking, with a bombarding energy source which emits a constant flux of energy ranging from 1.07 Kev through 21.77 Kev it is possible to analyze for elements from Na through U in a given sample.

X-ray analyses of this type are reliable (once calibrated), rapid (minutes), relatively less expensive than other methods (i.e., mass spectrometry), and reasonably precise (parts per thousand are routine in laboratories). These features hold true for geochemical applications in space, although the precision drops to about 1%. A testimony to this is the α backscattering experiment on the Surveyor soft lunar lander, and the nondispersive X-ray emission experiment for the Command-Service Module on the Apollo spacecraft.

The Turkevich, et al. experiment used energy spectra and intensitites of scattered α particules and protons from a Cm^{252} radioactive source to fluoresce elements in the lunar sample. This device was coupled with an array of silicon detectors. Its response range was from Boron (Z = 5) to Titanium (Z = 22) plus selected heavier elements.

This experimental package cannot be used for the Venus mission because the radiation source has a short half-life (163 days) and has a relatively low count rate (too low for a meaningful analysis during the less than two hour Venus entry) and the unit was designed to operate in a vacuum.

The Trombka, et al. experiment uses the high energy solar spectrum to fluoresce X-rays from elements at the lunar surface. The detector is a thin window proportional counter mounted on the orbiting spacecraft. Purpose of the experiment is to map geochemical abundances at the lunar surface. This experimental package also cannot be used for the Venus mission because it lacks a radiation source and was designed to operate in a vacuum.

VENUS PROBE APPLICATION

We propose that a gas filled X-ray detector of very small size (1 in. diameter cylinder, 3 in. long) can be made an integral part of the Venus probe pressure shell. A thin Be window of small diameter, supported by a network of high-strength graphite fibers, is the aerosol particle collecting surface on the exterior of the Venus probe (See Fig. 1). A radioactive source forms a concentric ring beneath and to the side of the Be window. Radiation passes out through the Be window and excites characteristic X-rays in the collected aerosol particles. Part of these X-rays pass back through the Be window into the gas filled detector and are counted. Shielding prevents source radiation from exciting the detector. A very thin membrane window isolates the gas filled detector from the radioactive source.

The graphite fiber network provides strength to the 5 mil Be window so it can withstand pressures to 100 atmospheres and excessive temperatures while maintaining about one atmosphere pressure within the detector. In the unlikely event of window rupture at the surface of Venus no damage can result to the interior of the Venus Probe because the detector, itself, is a pressure shell designed to withstand such a contingency. In any event, most of the detector's work will have been done before such high pressures are encountered.

INSTRUMENTATION

Gas filled detectors of the type described here are well developed. Supporting electronics, pulse height analyzers and other components necessary for data handling and transmission are proven devices, most with space flight history. Radioactive sources are commonly used for X-ray fluorescence analyses of minerals in the field on earth in instruments like this. Development of the reinforced Be window and supporting structures to withstand the harsh environment are the key development items in this experiment and are now underway.

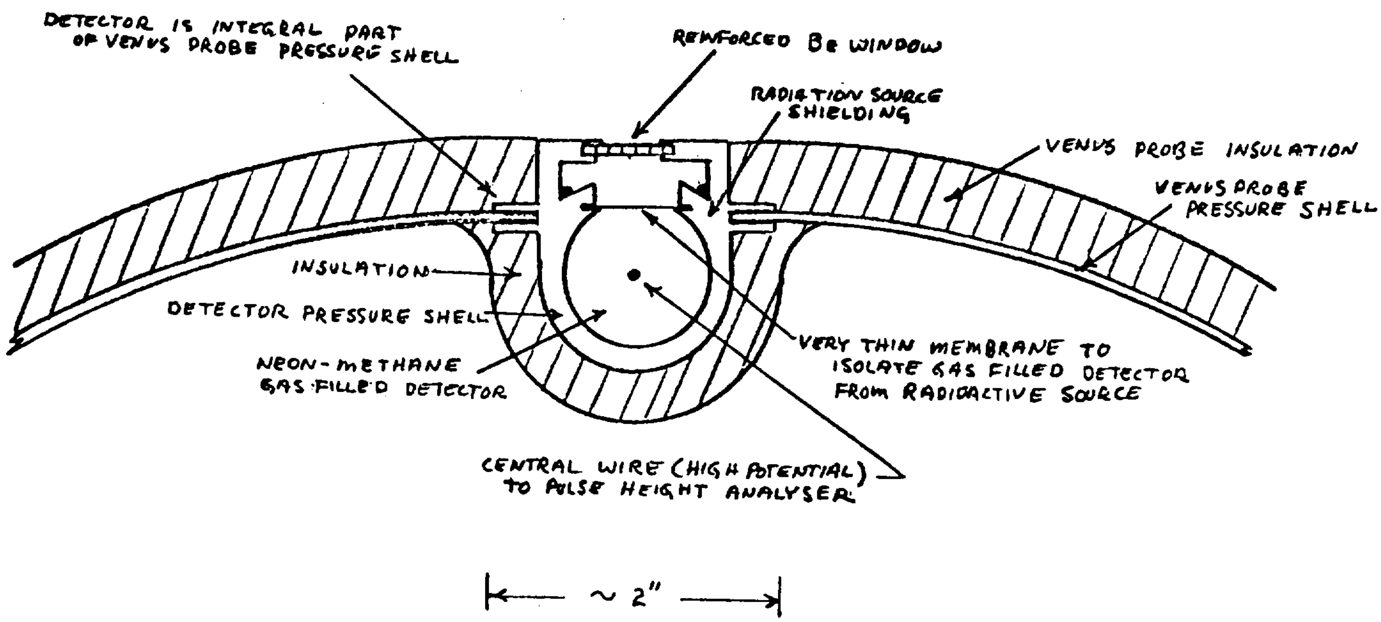


Figure 1. Cross Sectional View of Cylindrical Detector Mounted Inside Venus Probe Pressure Shell.

Nuclear Fluorescence Experiments

A tentative evaluation

D. M. Hunten
May, 1972

1. Gamma-ray excitation

This experiment has been suggested by N. Farlow and M. Blanchard of Ames. It is based on a commercial device (e.g. Kevex Corp.), which uses a cooled solid-state detector; typical analysis times are 1-10 hours. No information is available on the expected analysis time for a flight experiment. Farlow and Blanchard are correctly concerned about the feasibility of a thin window, which must:

a. transmit the fluorescent radiation

b. withstand 100 atm at 480°C

c. be tight against gas leaks.

Requirement (c) appears because the detector must be either a gas counter or a solid-state one; if the latter, it must be cooled and therefore insulated from the hot window by a vacuum. Farlow and Blanchard feel the gas counter to be more practical, but such devices are not normally required to operate at high temperatures.

One of the most interesting features of nuclear analysis is the possibility of measuring a layer of dust collected on a window or foil. But a descending probe is a remarkably poor vehicle for such collection, because the slipstream is directed upward, opposite to the force of gravity. This aspect of such experiments would require detailed testing with models in wind tunnels.

I feel that preliminary answers (at the very least) to the following questions are required before this experiment can be seriously considered.

1. Is a thin window feasible?
2. Is the detector compatible with this window and the high temperature?
3. Can a gas proportional counter give enough energy resolution?
4. If the window fails, can the safety of the probe be assured?
5. What is the analysis time?
6. Can a layer of dust be collected?

2. Alpha-particle excitation

A similar experiment has been flown on several Surveyors by a group led by A. Turkevich. He and Franzgrote have provided a preliminary analysis of how it might be adapted to a Venus probe. Both protons and γ-rays are to be detected. The source is 2 curies of ^{242}Cm (half life 63 days). Excellent sensitivity is shown for a 10-min analysis time. Thus, Question 5 above has been answered, but all the others remain, as well as:

7. Can the cooling actually be achieved, in a closed capsule, for a mere 1 lb? The failure on Mariner 6 is discouraging as regards reliability.

8. Is the proposed source (4 curies at launch) compatible with launch safety? Does it have to be as completely protected as the source in an RTG?

The SSG has the responsibility of recommending only those experiments that now exist, or are obviously state-of-the-art. I feel that all the relevant questions above must be answered, in at least a preliminary fashion, before the nuclear experiments could be included on a list of real candidates.

24. (Cont'd)

D. High Temperature Components

RESPONSE: 4-24-72

A family of electronic components and power source capable of operation at ambient temperature in the Venus lwoer atmosphere have been identified. A feasibility study and tradeoff analysis are planned and an RFP to industry is in preparation. Target date for RFP release is 30 June 1972.

RESPONSE: 6-5-72

Use of a family of components which operate at very high ambient temperatures continues to be a subject of investigation at ARC. Proposals for a contractor study are presently being evaluated. An award for such a study contract is contemplated for July 1972. Use of such components would appear to offer a higher degree of risk, pending extensive development and test so that this approach is viewed as a more likely candidate for the 1980 probe mission; therefore, the priority for this study is somewhat reduced.

24. (Cont'd)

E. Shock Layer Radiometer

RESPONSE: 3-29-72

A report entitled, "Atmospheric Composition of Venus by Shock Layer Radiometry" by E. Whiting and J. Arnold of NASA/ARC was distributed to the SSG members.

March 28, 1972

ATMOSPHERIC COMPOSITION OF VENUS BY SHOCK LAYER RADIOMETRY

Ellis E. Whiting and James O. Arnold

This note contains a brief discussion of the fact that certain constituents (N_2, Ar, CO_2, and perhaps H_2O) of Venus's atmosphere can be reliably determined by a bow shock layer radiometer experiment on board the large Venus-Pioneer entry probe.

The 1971 Planetary Atmosphere Experiments Test clearly demonstrated the ability to determine the composition of an unknown planetary atmosphere from radiometer measurements taken on board a probe vehicle entering the atmosphere at high speed. This was accomplished through a quantitative measurement CN violet, N_2^+ first negative and atomic oxygen spectral emission from the hot shock layer which formed as a result of the probe's interaction with the Earth's atmosphere. It is presumed herein that the reader is familiar with the techniques used in the PAET radiometer test.[1]

Figure 1 shows computed[1-3] shock layer spectra for three points along a trajectory in Venus's atmosphere for an entry speed of 11 km/sec. The ambient conditions for each point are specified on the figure, as is the assumed ambient composition. It may be seen in figure 1(a) that the spectrum at the highest speed and temperature is dominated by O and C atomic line emission. At the lower speeds and temperatures [figs. 1(b) and 1(c)] CN violet and C_2 molecular band emission becomes quite prominent. Argon lines are also present, but their emission is relatively weak for all three conditions.

Figures 2(a) and 2(b) illustrate the predicted effects of ambient gas composition changes on the CN violet and C_2 Swan spectral intensities at

3883 and 5165 Å, respectively. These intensities are close to the peak values predicted to occur during the entry. The solid lines shown on the figure specify the intensity variation for a biconstituent CO_2-N_2 mixture. The verticle bars attached to the solid lines encompass the intensity changes resulting from argon dilution with the N_2 percentages held constant. As may be seen, Ar dilution (to as high as 9%) has only small effects on the CN violet and C_2 Swan emission at the peak intensity conditions.

Figure 2(b) clearly shows that radiometer data on CN violet at the peak intensity condition would easily lead to a reliable determination of the N_2 concentration in Venus's atmosphere.

Calculations similar to those discussed above show that the C_2 Swan emission at levels at 1/10 of the peak intensity values are sensitive to the thermodynamic effects of Ar dilution. This is illustrated in figure 3(a), where the solid lines correspond to a fixed N_2 concentration and variable CO_2-Ar concentrations. The increased temperatures arising from the Ar dilution causes enhanced C_2 Swan emission at this trajectory point. Thus, radiometer signals at the ∿0.1 peak intensity levels could be used to specify the Ar concentration corresponding to the N_2-CO_2 concentrations obtained from the peak intensity radiometer data and figures 2(a) and 2(b).

Similar calculations indicate that water vapor in Venus's atmosphere could be sensed by a radiometer viewing OH shock layer emission at 3064 Å.

The CN and OH signals decrease nearly linearly with the ambient N_2 and H_2O constituents, respectively. The lower limits of detection occur when the CN and OH signals sink into the underlying emission continuum. These lower limits are presently estimated to correspond to approximately 0.01% N_2 and 0.5% H_2O. (Recall that the PAET radiometer test reliably measured the 0.03% CO_2 in Earth's atmosphere by observing CN violet emission.)

At this time an eight-channel radiometer, with passbands preselected to observe band emission from OH at 3060 Å, CN at 3883 and 4216 Å, and C_2Swan at 5165 Å, appears to be very desirable. Four background channels would also be included to ensure that the observed spectrum was properly understood. Such a radiometer could be mounted external to the heat shield as sketched in figure 3(b). With this configuration only a very small penetration in the aeroshell would be required for the leads from the radiometer channels to the internal electronics.

In summary, it is concluded that the same shock layer radiometry techniques which were very successful for the PAET could be employed to reliably determine the presence of N_2, noble gases, and water vapor in the Venus atmosphere, and perhaps other constituents as well. Consequently, it is strongly recommended that a shock layer radiometer experiment be flown on the large Venus-Pioneer entry probe.

REFERENCES

1. Seiff, A.; Reese, D. E.; Sommer, S. C.; Kirk, D. B.; and Whiting, E. E.: (Results from the PAET--A Trial in the Earth Atmosphere of Measurements of an Unknown Planetary Atmosphere During High-Speed Probe Entry.) ICARUS article in preparation; draft available from A. Seiff upon request.
2. Arnold, J. O.; Whiting, E. E.; and Lyle, G. C.: Line by Line Calculation of Spectra from Diatomic Molecules and Atoms Assuming a Voigt Line Profile. JQSRT, vol. 9, no. 6, 1969, p. 775.
3. Whiting, E. E.; Arnold, J. O.; and Lyle, G. C.: A Computer Program for a Line-by-Line Calculation of Spectra from Diatomic Molecules and Atoms Assuming a Voigt Line Profile. NASA TN D-5088, 1969.

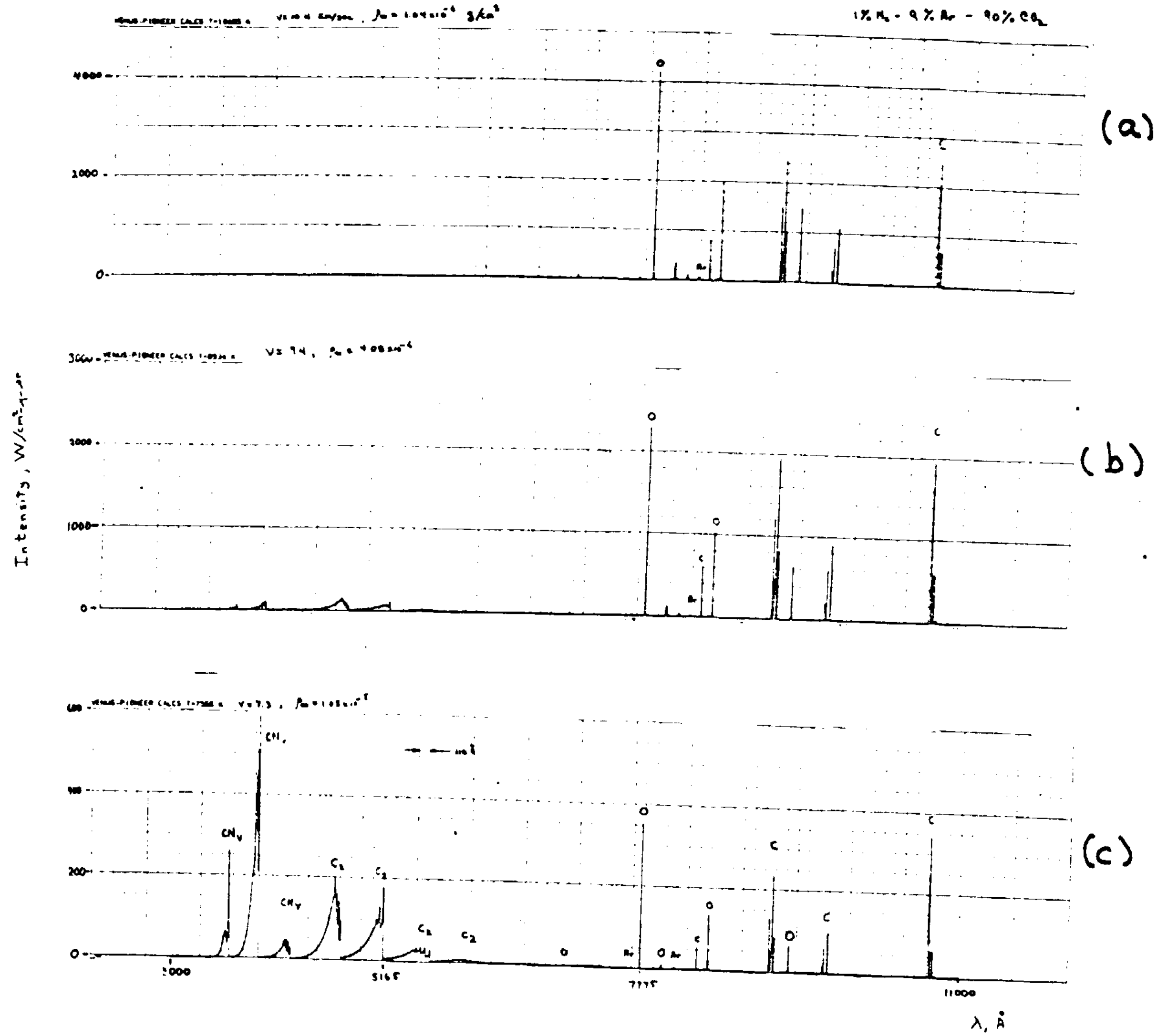


fig 1. Predicted shock layer spectra for three points along a trajectory in an assumed Venutian atmosphere. Entry speed = 11 km/sec. The spectrum of fig 1(a) at 10495°K is dominated by atomic line emission. At lower speeds and temperatures, molecular emission becomes prominent. The assumed ambient composition was 1% N_2, 9% Ar, 90% CO_2

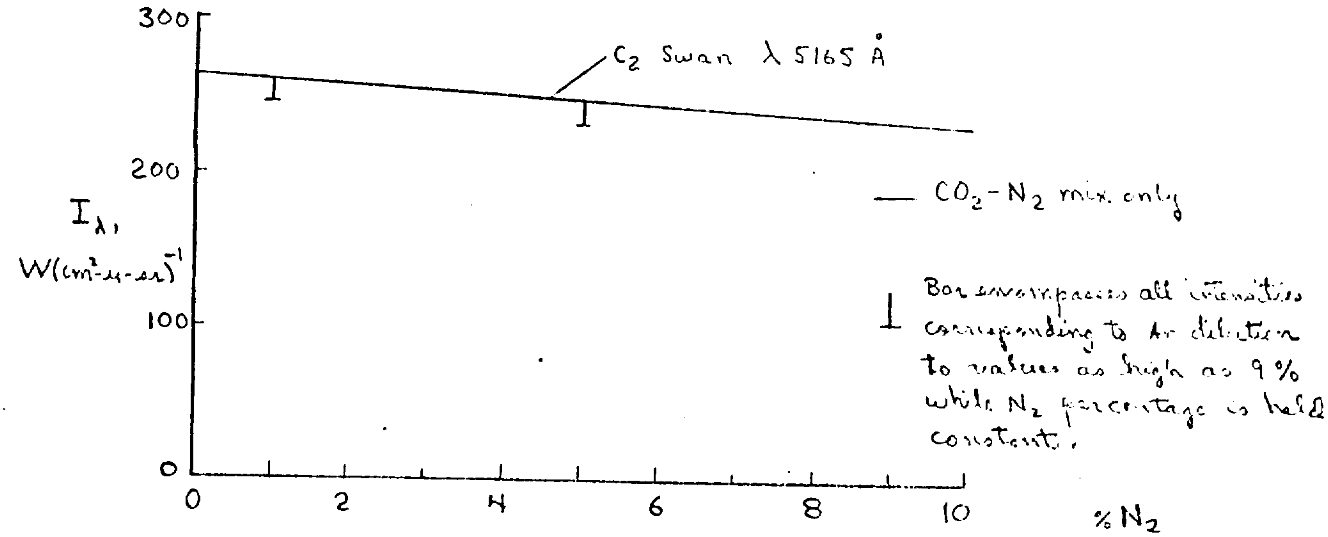


Fig. 2(a) Predicted effects of ambient gas composition changes on C_2 Swan spectral emission from probe shock layer. CO_2-N_2-Ar constituents were considered. Predictions correspond to a trajectory point at which the peak C_2 Swan spectral intensities are expected to occur for an entry speed of 11 km/sec. As may be seen, at the peak intensity level, Argon dilution has only a small effect on the C_2 Swan spectral intensities.

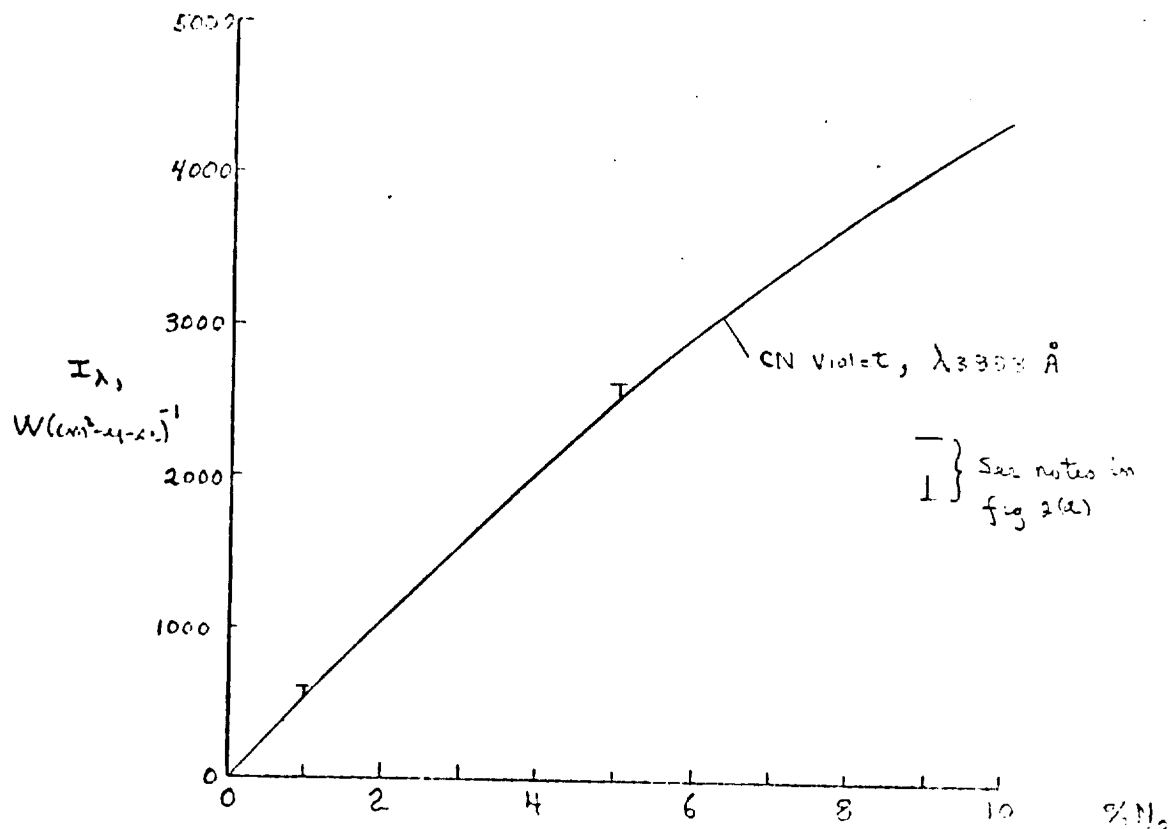


Fig. 2(b) Predicted effects of ambient gas composition changes on CN violet spectral emission from probe shock layer. Gas constituents as in fig 2(a), and the curve again corresponds to a trajectory point at which the peak CN violet spectral intensities are expected to occur. Note that the argon dilution has only a small effect on the CN violet spectral intensities.

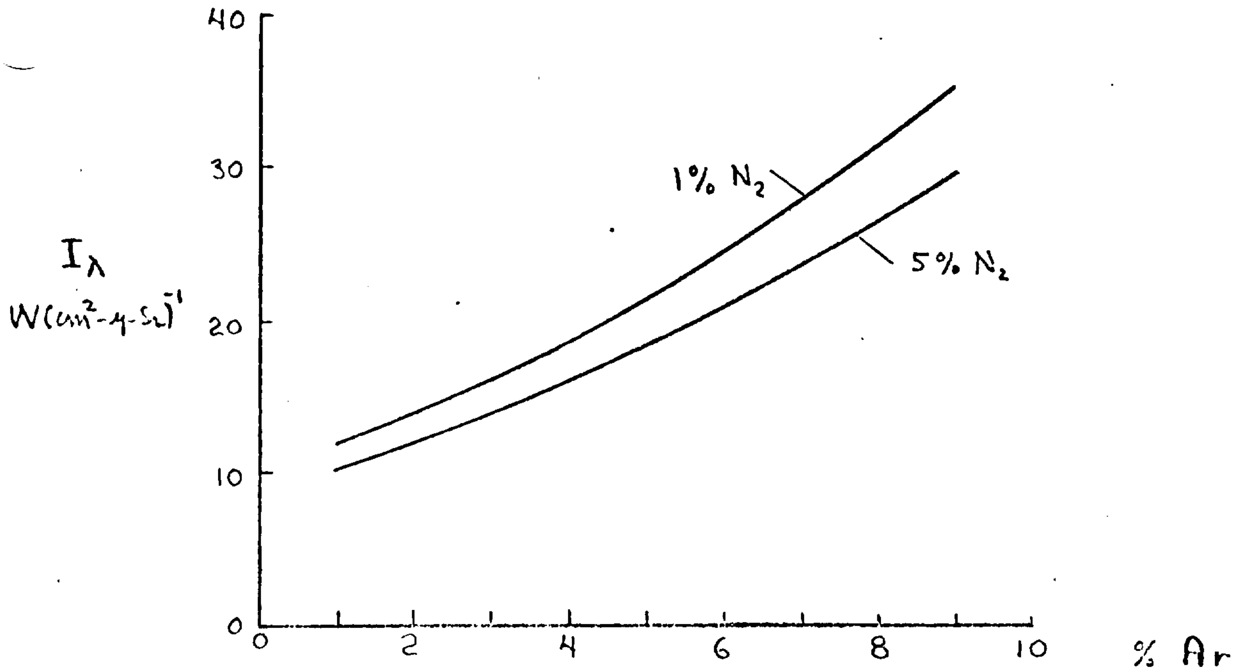


Fig 3(a) Predicted effects of ambient gas composition changes on C_2 Swan spectral emission from probe shock layer. Predictions correspond to a trajectory point at which the C_2 Swan emission is about 1/10 that shown in fig 2(a). Here the thermodynamic effects of argon on the C_2 Swan intensities can be used to specify the argon content in Venus' atmosphere.

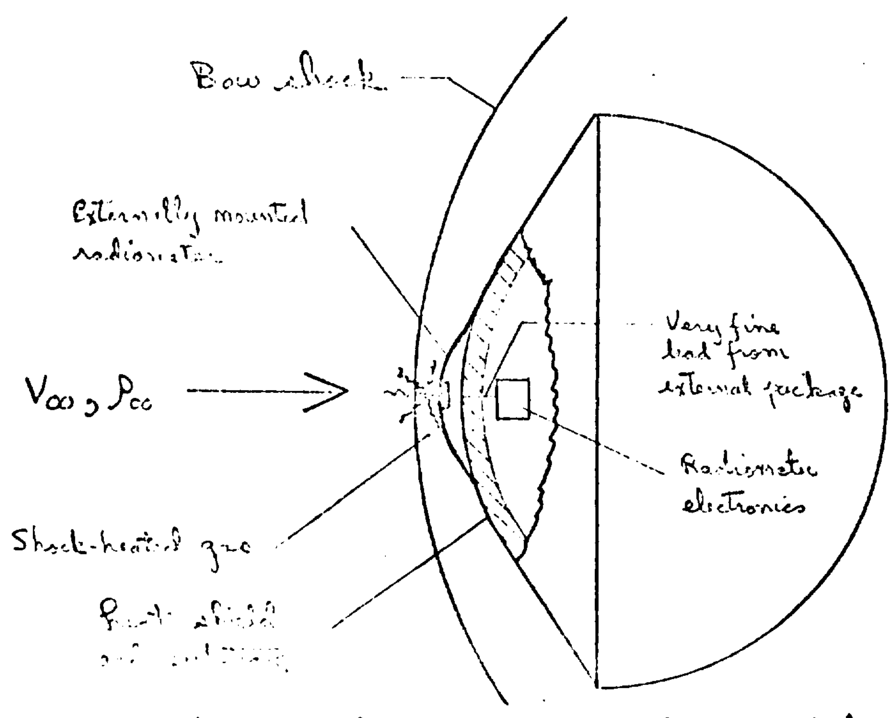


Fig 3(b) Preliminary design for externally mounted radiometer. This design also eliminates any large window opening in the probe's aero-shell.

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24. (Continued)

F. IR Radiometers

RESPONSE: 6-5-72

ARC is studying a number of alternate conceptual IRR designs for solar flux detector and a downlooking radiometer. Several look promising and the general feasibility of this class of device does not appear to be in serious doubt. See next paragraph for report on an ARC developed radiometer and flux detector.

R. Boese/J. Pollack have completed initial design of both a Solar Radiometer and Infrared Radiometer. The former, to study solar energy deposition, is a 4 channel device covering the 0.3 to 2.5μ band. A single, chopping mirror is used to alternately look up and down (∿ +60° from the horizontal) through a sapphire window. The Infrared Radiometer is a 3 channel device (5.8 - 7μ, 7.6 - 8.8μ, 14 - 16μ) which is to look downwind only. The first 2 channels are to be used for water vapor detection, and is thus a backup to the mass spectrometer. The second and third channel together would be used for cloud detection and thus be a backup to the nephelometer. Some breadboarding of the chopper for the IR Radiometer has been completed. R. Boese is available for more details if desired.

24. (Cont'd)

G. Glow-Discharge-Optical Spectrometer

RESPONSE: 3-29-72

Distributed a report entitled, "Atmospheric Composition of Venus by Glow Discharge-Optical Spectrometery," by W. Davy, et. al., of NASA/ARC.

March 28, 1972

Atmospheric Composition of Venus By Glow Discharge-Optical Spectrometry

W. C. Davy, J. J. Givens, J. O. Arnold, E. E. Whiting, and D. L. Ciffone

The composition of Venus' atmosphere and perhaps Venus' clouds can be determined by a glow discharge-scanning spectrometer on board the Venus-Pioneer probe. The underlying concept of the experiment is that the characteristic emissions arising from an electrical discharge passed through a sample of ambient gas can be spectrally analyzed to specify its chemical composition. Laboratory tests are currently being made to evaluate how accurately the distributions of CO_2, N_2, Ar, H, Hg, Cl, Al, and Si from above the cloud tops to the Venusian surface can be determined with such an instrument. Preliminary results of this study are discussed below.

Figure 1 shows the near UV - Visible spectrum emitted by a mixture of 90% CO_2, 6% N_2, 1% A, 1% Ne, 1% He and 1% O_2. The spectrum is from the positive column of the glow discharge and extends from about 2800 to 4800 Å, with a resolution of about 10 Å. Several N_2 second positive and CO bands are quite prominent, which means the CO_2 - N_2 mole fraction can be easily determined at all altitudes. Further testing is necessary to find the applied voltage, discharge tube pressure, etc., that best enhances the Ar lines near the cathode. Similar spectra taken in the vis- near IR region show that strong mercury lines appear near 8000 Å. These are most probably due to contaminants in the electrodes. Therefore, additional tests with high purity electrodes will be made to eliminate this source of mercury and determine the sensitivity of these measurements to mercury compounds in the atmosphere.

A Sketch of a possible glow discharge scanning spectrometer is shown in figure 2. The spectra from both the anode and cathode regions of the discharge tube are scanned over a 2000 Å region at 10 Å resolution. The precise spectral region for the scan will be selected after further testing, but will probably lie within the 3000-8000 Å region. The voltage can be stepped during the scan to enhance desired spectral features.

The instrument weighs about 3-4 lbs, and the average power consumption is about 3 to 4 watts during each scan. A scan will only require about 15 seconds operation. The gas sampling system shown schematically in figure 3 incorporates an evacuated dump tank, with a volume of about 1/4 liter, and appropriate valving to give a pressure in the discharge tube of about 10 mm H_g. Approximately 10 to 15 scans can be made before the dump tank pressure is too high to prevent the discharge from occurring.

If three channels are placed in both the cathode and anode regions, each scan will produce about 1200, 7 bit data words. If the data are transmitted at an average rate of 10 bits/sec, a scan can be made every 15 minutes. The instrument is very rugged and should easily survive the landing, so that several scans can be made on the surface.

The discharge tube would be filled with a known gas sample prior to Earth launch to enable calibration scans to be made during the journey to Venus.

Finally, a "bread board" or bench model of this instrument will be constructed in the coming months to fully evaluate its potential for determining the composition of the atmosphere and perhaps the clouds of Venus.

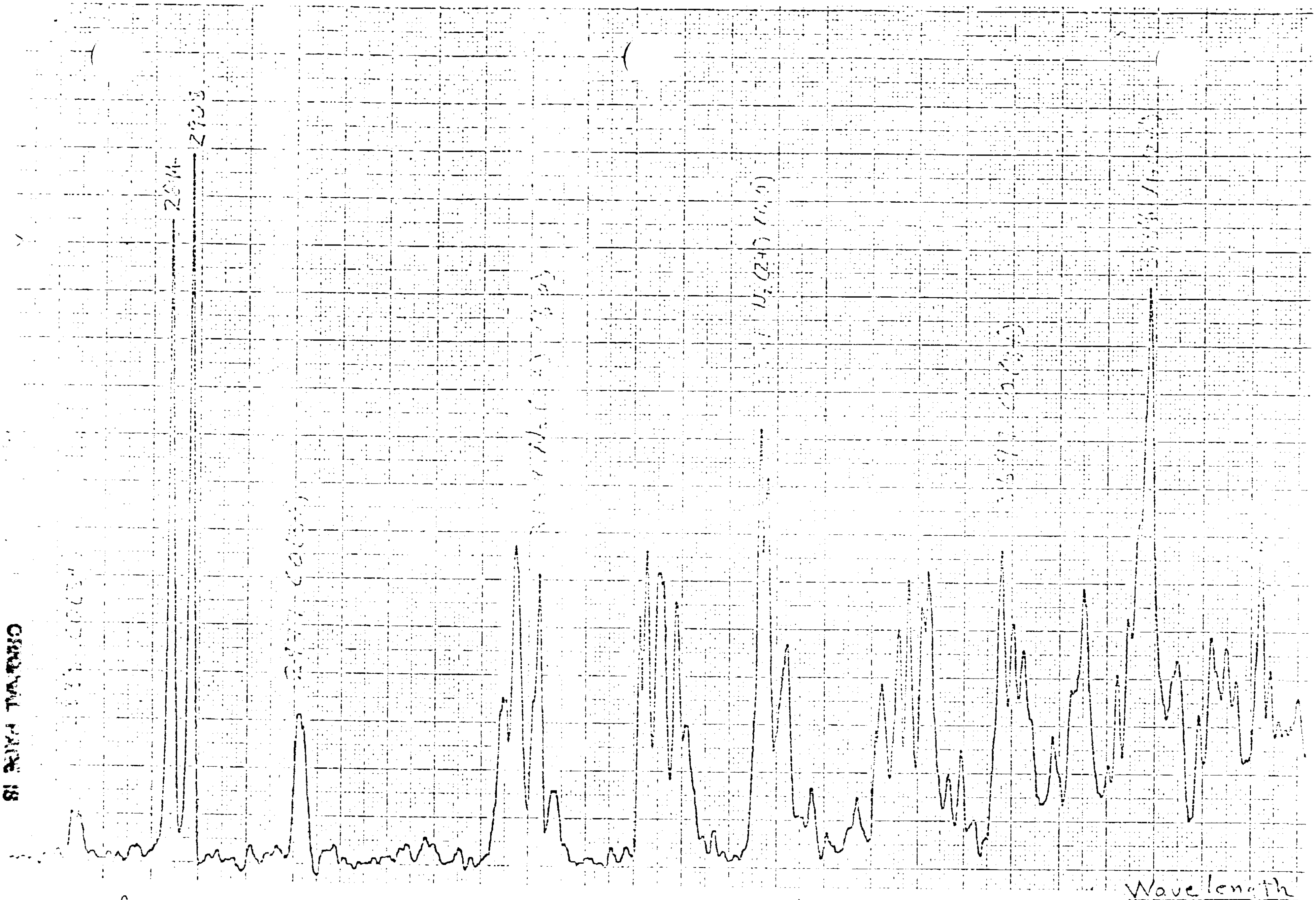
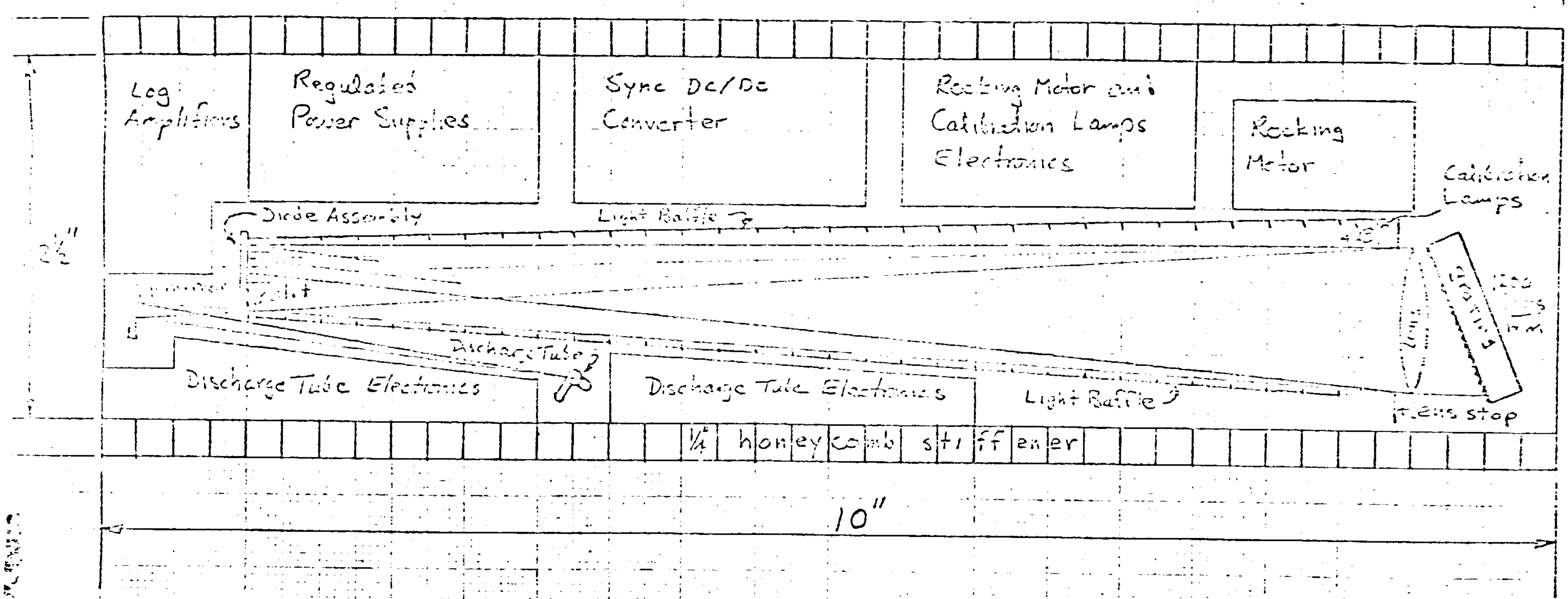
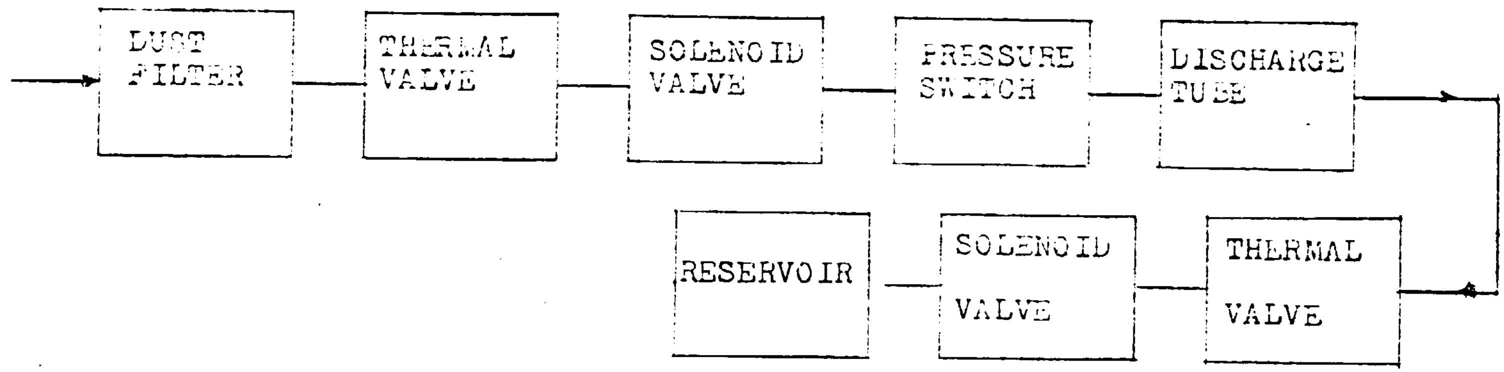


Figure 1. Characteristic emission arising from an electrical discharge passed through an assumed Martian atmosphere of 90% CO_2, 6% N_2, 1% Ar, 1% Ne, 1% He, and 1% O_2. The prominent N_2 and CO bands can be used to specify the CO_2 and N_2 mole fractions.

Figure 2. Full scale drawing of a glow discharge-scanning spectrometer whose purpose is to measure mole fractions of certain constituents of Venus atmosphere. Scanning is achieved by rocking the grating and photodiodes are used as sensors.





COMPONENT	WEIGHT, lb	VOLUME, in^3	POWER
FILTER	.2	1.	PASSIVE
THERMAL VALVE (2)	.025	.03	.1 watt-hr
SOLENOID VALVE (2)	.05	.75	10 watts for 50 msec
PRESSURE SWITCH	.4	2.	.15 watt
RESERVOIR	.5	16.	PASSIVE
APPROX. TOTALS	1.2	20	

Fig 3: Schematic diagram of gas sampling system for glow discharge tube using LiOH to absorb CO_2. Valves are state-of-the-art equipment used in Viking Project. System seals for transient to be opened by thermal valves.

24. (Cont'd)

H. Accelerometer/Miniseismometer

RESPONSE: 6-5-72

The Project Office has investigated the use of existing flightworthy accelerometers in a dual mode to provide both high-G entry deceleration and low-G seismic surface noise. Two potential sources for such devices have been identified, as described in response below, and it appears quite feasible to perform the seismic noise measurement, using the entry science accelerometer with minimal modification and cost.

Dr. Block, UCSD and Diax, Inc., La Jolla, California, has developed a quartz fiber accelerometer, that has extremely linear and flat response which makes it ideal for applications such as seismic measurements. His Hi-QTM instrument has been tested extensively over several years from tidal to seismic frequency and found to have low noise in comparison with other geophysical instruments. Unfortunately, the outer diameter of the existing production instrument is 8 inches. A smaller instrument with expected performance equal to the Hi-QTM design is under construction. Its diameter is 4-3/4 inches. Dr. Block said that to miniaturize this instrument to a size and weight that could be acceptable for a Venus probe, say one or two pounds and one or two cubic inches, may not be feasible within the time span or cost constraints of the Pioneer Venus program. He did suggest, however, that his instrument could be built for possible application to the large probe, with a mechanical full scale of 500 g and an electronic resolution of 10^{-6}. He suggests that the instrument can double as a sensor in an inertial navigation system and as a seismometer on the Planetary surface. Again, the flight instrument would be a development item.

The Project Office has also looked into the application of the Bell Aerosystem Company accelerometer as a seismic instrument. Bell has used a flight configuration model VII three-axis accelerometer package as the measuring device for an MIT seismic acceleration system. This particular system amplified "g" signals from 0.01 cps to 200 cps. The Bell people explained that a new Model X accelerometer, single axis, including all electronics and configured to double as a miniseismometer, could be built in flight version with very little development in an envelope of approximately one cubic inch, weight - 8 oz., and power of about 0.7 watts.

We are also looking at the Viking seismometer. It will have the advantage of being a flight-qualified instrument already developed.

24. (Cont'd)

I. Pressure Gauges

RESPONSE: 6-5-72 by A. Seiff

Work to date has been confined to developing requirements and survey existing hardware. Test data has been furnished by Vendors on a number of off the shelf instruments and several appear suitable, with minor modification, for the Venus Probe missions. Study of alternatives will be continued.

24. (Cont'd)

J. Radar Mapper (Orbiter Mission)

RESPONSE: 6-5-72

A study of requirements and potential design for a radar mapping altimeter, sharing the X-band RF occultation experiment transmitter and a despun pointable antenna is ongoing at ARC. The following preliminary report was generated by the Pioneer Venus Project Office.

The Pioneer Venus Project has investigate the problems associated with providing an adjustable X-Band antenna on the orbiter. This antenna would be used for radar mapping. The results are as follows:

1. The antenna assembly conceptual design was based on the following general assumptions:

   a. RF source - 3.5 W at 8400 MHz

   b. Required gain - 24 dB or 30 dB min.

   c. Polarization - circular

   d. Positioning - Mechanically despun and rotatable out of the spin plane from 0-45° minimum.

   e. Antenna alignment - ±1/2°

   f. Use - dual: Telemetry to Earth and Radar mapping from a Venus orbiter.

2. The design selected has the following general characteristics: A one or two-foot parabolic reflector is directly fed from a wave guide supported, circularly polarized feed. Two rotary joints allow two axis pointing of the antenna.

3. The parabolic reflector would be constructed out of 2.5#/cu ft. aluminum honey comb, 1/2" thick, sandwiched between two layers of reinforced fiberglass plastic laminates. Each layer would be constructed out of an electrical grade 120 double warp fiber-glass cloth laminated with an epoxy matrix mixed with a UV inhibiter. The skins would be essentially void free. The outer most skin would be flashed with at least 5 skin depths of sputtered aluminum. Aluminum honeycomb would be used in order to improve the thermal conductivity of the reflector. Thermal distortion with aluminum should not give use to more than ± 0.01 in. deflection from edge to edge with the worst case Sun illumination. The weight of this one-foot diameter reflector would be about one pound; with hardware, about 1-1/2 pounds.

24. J. (Cont'd)

4. The antenna feed would be constructed out of aluminum waveguide with a standard flange, RG-52U, at one end. The feed would taper from the rectangular end to a circular cross section. A quarter wave piece of rexolite plastic would generate the circular polarization required. The circular waveguide would then taper down to approximately 1/2 the diameter and a teflon feed plug with a metalized splash plate would complete the feed assembly. The weight would be dependent on the material used for the feed; Aluminum would be about 2 lbs., magnesium about 1.5 lbs. The focal point to reflector diameter ratio would be 0.7 or 8.4 inches for the one-foot reflector. The design feed pattern -10.8 dB edge directed illumination and gives rise to an efficiency of approximately 60%. The half power beam width for the one-foot reflector would be 8.1° and for the two-foot reflector approximately 4°.

5. The vertical deflection would be accomplished by use of 90° steppe motor, connected to the flat side of the waveguide feed rotary joint. The 28 volt four phase steppe motor would be connected to a 60:1 gear box and a position potentiometer. The torque multiplication factor is about 80%, resulting in a 40in./oz. available for positioning the antenna in the vertical plane. The weight of the torque motor and gear box would be 5 ounces. The total power consumption for the vertical drive is 8 watts, with a very short duty cycle. Both the vertical drive motor and associated electronics have been space qualified.

6. The total weight for the one-foot reflector that is despun is approximately 9 lbs., with the radius of gyration of 4". At 20 RPM the energy required to despin to zero would be 1 joule. The time required to despin for 20 RPM to zero would be 10 seconds. The despin motor picked develops over 3 in./oz. of torque at 300 RPM. The despin motor would drive a 5:1 gear box at the base of the azimuthal rotary joint and antenna pedestal. The despin assembly would be mounted on the top of the spacecraft and on the spin axis. The power consumed in the servo drive motor and electronics would be about 0.01 watts for continuous duty. The motor is brushless, dual redundant and space qualified for Apollo; a lifetime in orbit for five years is a very high probability. The servo motor weighs about 4 pounds including the drive electronics.

7. The rotary joints used in the antenna structure would weigh about 2-1/2 lbs. apiece, if manufactured out of Aluminum and about 1-3/4 lbs. for magnesium. The VSWR at 8400 MHz would be 1.1:1 with a 1.02 Wow. The insertion loss would be 0.2 dB with a 0.05 dB Wow.

8. Bearings for space use have been supplied by both Ball Brothers and Bartemp. Lubricants and special coatings are available from numerous sources. All items chosen for this despin assembly will all be flight proven and fully qualified.

9. Due to the very low ratio of spinning to non spining inertia, the spacecraft will couple to the despinning antenna by a factor of $\sim \frac{1}{10,000}$. No correction of the spacecraft spin rate is anticipated for at least two years. However, bearing friction increases may degrade this estimate, and spin up orientation may be required. In fact, failure of the bearing may lock the X-band antenna to the spacecraft spin. A backup "S" band transmitter should be included in the communication system design to provide a redundant telemetry link.

10. The duplexer would be a fairly straight forward design using quarter wave sections and pin diode switches to protect the receiver from damage. Some additional filtering in the duplexer design would be required to keep the spacecraft generated "S" band signal out of the "X" band radar receiver. The weight for this unit would be under 2 lbs. Similar units have been built and qualified for space applications.

11. A summary of the antenna assembly weight is listed below. For the two-foot antenna (approximately 30 dB gain) only the weight of the reflector would change significantly. The structure and bearing weight would not change significantly and the drive motors could easily handle the extra load.

Weight Breakdown (lbs.)

Reflector (1 or 2 ft.)	1.5 - 5.5
Feed	2.0
Structure	1.1
2 rotary joints	5.0
Stepper Motor	0.3
D.C. Servo Motor and Drive Electronics	4.0
TOTAL:	13.9 - 17.9

12. Prices for such an antenna assembly vary as to the degree of confidence required. This despun assembly completely built, qualified and integrated into the spacecraft by Lockheed, TRW, Hughes or any large Aerospace firm would cost over 2 million dollars, assuming one flight unit plus one backup. If built and qualified at Ames the price would be about $400,000. The integration costs associated with the spacecraft contractor would probably run over one million.

24. (Cont'd)

K. Cloud Particle Analyzer

RESPONSE: 6-5-72

Dr. Knollenberg reported in a recent seminar at ARC, the development and impending flight test of a direct backscatter particle analyzer which appears to be a likely candidate for the Venus probe missions. While it by no means reduces interest in his more sophisticated 3 channel laser extinction device, it does offer a simple straight forward alternative and thus helps to allay concern over the complexity of integration and optical alignment of a cloud particle analyzer. Dr. Blau, however, who has flown an instrument similar to Knollenberg's backscatter device, extensively in Earth Atmosphere, expresssome doubt that this approach is suitable for the Venus missions. Dr. Knollenberg's tests this summer will be watched with great interest, and in-house study of the particle analysis problem is to continue at ARC.

A report entitled, "Comments and Recommendations on Knollenberg Particle Size Spectrometer for the Pioneer Venus Probe" by A. Seiff was distributed to the SSG members.

Comments and Recommendations on the
Knollenberg Particle Size Spectrometer
for the Pioneer-Venus Probe
(Response to action item from SSG meeting of April 24-25, 1972)

At the April 24-25 meeting of the SSG, the writer accepted the task to meet with Dr. Robert Knollenberg for the purpose of evaluating the complexity and practicability of his cloud particle size spectrometer for use on Pioneer-Venus. As a result, Dr. Knollenberg was invited by the Project to visit the Center on May 19, 1972. Representatives of the Project and the Ames Electronic Instrument Branch took part in the discussions.

As a result of this meeting and an examination of the instrument hardware shown by Dr. Knollenberg, the following conclusions were reached by this writer:

(1) The value of the instrument to the investigation of the Venus clouds is very high. (The need for particle size measurements in cloud characterization is illustrated by the contrast between fog and falling rain. The former has high opacity and small water content, while the latter is transparent, but of high (relative) water content. Of the instruments we have considered, only the particle size spectrometer could correctly characterize these two conditions.)

(2) The instrument weight has, at 25 lbs, apparently been badly overstated in previous discussions in the SSG. Although Knollenberg did not have a total weight figure, it appeared all the essential instrument components, which he brought along and placed on the table, would sum to the order of 5 lbs.

(3) The power requirement (20 watts) is large, and would require about 3 lbs of the spacecraft battery if the instrument were operated continuously through the descent. The option apparently exists, however, to turn the power on only when readings are to be taken. For Earth clouds, a size spectrum is collected in about 1/8 second. Then power could be left off for a period of about 15 seconds (see below) until the next reading is taken.

(4) The data quantity needed is manageable (about 1/10 of the main probe data capacity) if readings are taken no more frequently than every 15 seconds. (This would correspond to altitude resolution of 375 m at 25 m/sec descent velocity.) The use of an adaptive system to insure that data are sent only when the probe is in the cloud would appear highly desirable.

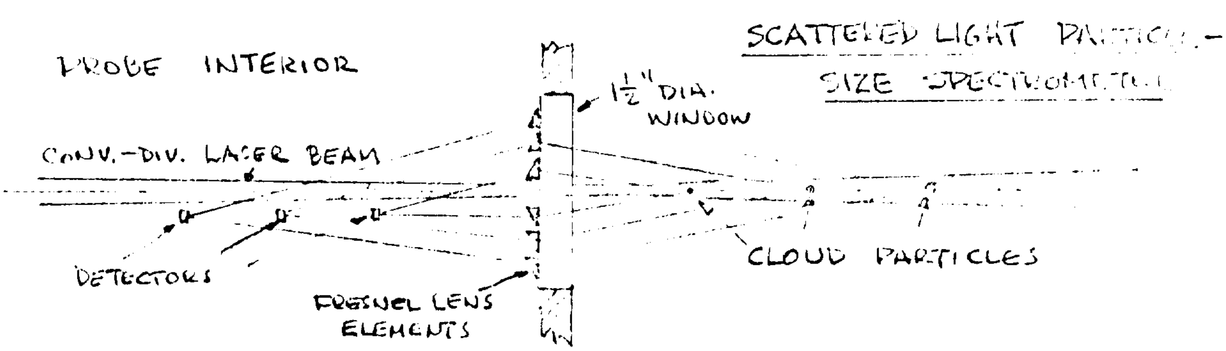
(5) The most critical aspect of the instrument for remote planetary applications is the optical alignment. For the small size range channel (1 to 10μ), a translation of the laser light pencil by 0.018 mm over the face of the objective lens causes the image to start to move off the detectors. In the face of the expected thermal distortions, vibration, and aerodynamic loading to which the optical arms extending outside the spacecraft would be exposed, this extreme alignment sensitivity appears to put the imaging type spectrometer in the unacceptable risk category. However, a second version of the instrument has also been developed which measures particle diameter from pulse height analysis of beam extinction due to single particles. Three single, standard size detectors are used, instead of the array of 14 miniature detectors 0.1 mm square, so that alignment problems are not critical. Knollenberg has, in addition, a design with no projecting optical arms which he intends to build and test for Pioneer-Venus. It is a three size-range instrument instrument, which directs a laser beam outward through a window in the probe surface. Scattered light from individual cloud particles is measured at three levels of beam cross section and illumination intensity, each of which favors a different range of particle sizes. The pulse height analyzer used in the extinction mode of the present instrument would be used here also. A sketch of the optical arrangement for this option is attached.

Recommendations: (1) A particle size spectrometer should be flown on the Pioneer-Venus main probe. (2) From the standpoint of operational reliability, based primarily on recognized alignment problems of the imaging type instrument, it appears that the spectrometer selected should be either an extinction type instrument or a single particle scattering instrument, both of which are capable of diameter measurements through pulse height detection.* (3) Because of weight and data rate limitations, it does not appear feasible to include particle size spectrometry in the miniprobe payload.

Alvin Seiff

Alvin Seiff
May 22, 1972

*Knollenberg stated that he agrees with this conclusion.



24. (Cont'd)

L. Nephelometer

RESPONSE: 4-24-72

ARC will support the fabrication and test of the nephelometer designed by Dr. Blamont to determine feasibility of such an instrument for the small Probe. Specific arrangements for scientific and/or engineering support will be made with Dr. Blamont at the time of the 3rd SSG meeting and work will begin at that time. Target date for testing an engineering model is 31 July 1972.

RESPONSE: 6-5-72

The ARC Instrument Development Branch has been studying Prof. Blamont's conceptual design for a small probe nephelometer. The preliminary conclusions of this study are:

(a) Such an instrument is entirely feasible within the constraints of the small probe.

(b) 2 - 4 wavelength analysis does not appear to offer significantly better likelihood of particle identification than can be expected from a single channel device.

(c) A backscatter device using an interference filter and refractive collecting optics appears to offer the best performance for a simple single channel device.

(d) The electronics and data processor for up to 4 channels can be readily implemented in a small probe scale instrument.

(e) A suitable light source for the multichannel approach is not readily available and would require some development. (See Dr. Ragent's preliminary summary report of 5-30-72 for additional detail.)

FEASIBILITY OF INCORPORATING A NEPHELOMETRY EXPERIMENT INTO THE VENUS-PIONEER MINIPROBE MISSION

Summary, Conclusions and Recommendations

I. Objectives

A. The major objectives of the experiment which appear feasible are:

1. The measurement of the location of layers of particles (clouds) as a function of altitude on <u>both</u> the dark and light sides of the planet. Light aerosol layers will be readily distinguishable at high altitudes on the dark side only.

2. The measurement of solar background radiation (at the orientation of the viewing system) for one or a few wavelengths as a function of altitude. One of these wavelengths would be identical with the source wavelength. Several other wavelengths (including, for example, the Hg I 2537 Å line) could be monitored at a reduced rate.

B. Other objectives which appear more questionable are:

1. The characterization of the number density and properties of the scattering particles.

2. The determination of the presence and concentration of the presence of mercury in the atmosphere of Venus, as a function of altitude, using an on-board active light source (based on the lack of availability of a suitable source of radiation at 2537 Å).

II. Design Considerations

A. Body Location

The only restrictions on body location imposed by the experiment are to avoid sampling from the regions of major body-flow interaction, e.g. the aft body regions and the flow within a few inches of the forebody skin. Viewing regions shielded by removable plugs of heat shield material looking out the forebody, to the side, are acceptable.

B. Windows

On-board heating of the window during descent and the choice of optical configurations minimally sensitive to fogging and dusting are required. A calibrating, light-emitting diode should be incorporated into the configuration, if possible, to calibrate the window transmission. Small windows (less than 1cm dia.) may be used for reasonable source strengths.

C. Operating Wavelengths, Scattering Angles, Signal Strengths, Backgrounds

Requirements for the availability of sources and detectors dictate the use of the visible regime (including the near IR). Except for the possible use of the Hg I 2537 Å line, there is no overriding advantage of one wavelength over another in the visible region of the spectrum.

Because the scattering cross-section for a polydispersion of particles with a 1μ modal radius and narrow range of particles sizes oscillates rapidly with visible wavelength for scattering at wide angles, it will be very difficult to interpret the nature and size of the particles from measurements made at only a few wavelengths. Since the use of many wavelengths is not practical, very little additional information is gained by the use of two or four wavelengths rather than one. An additional wavelength, if desired, may be most conveniently derived by frequency doubling the output of the solid state laser using a solid state doubler.

Since scattering angles in the forward direction are precluded by available configurations (unless mirrors are erected outside the vehicle skin during descent), rearward (rather than sideward) scattering is to be preferred from an intensity viewpoint. Scattering at angles of 80 to 120° would be preferred if polarization measurements were to be involved.

Calculations of signal to background ratio for night sky and bright cloud backgrounds indicate that both aerosols and cloud layers may easily be detected on the night side. Light aerosols can probably not be distinguished, but cloud layers may be easily measured on the bright side of the planet. These calculations were performed using scattering coefficients of 20 km^{-1} and 0.1 km^{-1} for clouds and aerosols respectively, and scattering data calculated for appropriate polydispersions by Deirmendjian. The calculations indicate that on the night side the sensitivity to particle density will be limited by the probability of having sufficient scatterers (more than 1) in the sampling volume during the light flash.

D. Components

Standard, commercially available components are available or components are easily manufactured for all items with the possible exception of the light source and detector. A solid state GaAs laser operating at high power (more than 1 watt during the pulse) in the near IR is recommended and commercial types are available, as are frequency doublers for multi-wavelength operation. Flashable multiple wavelength spectral discharge source operating at specific atomic absorption wavelengths do not appear to be commercially available (at least were not discovered in this study) and remain to be developed. Solid state diode (PIN) and silicon avalanche types of detectors are available, and a new rugged, miniaturized photomultiplier type has appeared on the market, but is not completely space-qualified.

Refractive collecting optics appear simpler and less bulky than reflective collecting optics and narrow band interference filters at fixed wavelengths appear easier to package than dispersive optical systems.

E. Data Processing, Electronic Considerations, Power Budget

The total data bit budget of about 8000 bits during descent will provide an adequate capacity for the experiment. Depending on the final design of the experiment, the allotment of 5000 bits for the light scattering measurement and 3000 bits for background measurements or other data, and the use of 10 (or 11) bits per reading allows a total of about 500 data points for a one-wavelength system, or correspondingly fewer for multiple wavelengths. The actual formatting will depend on the detail desired, preprogramming of data rate using an assumed altitude-velocity profile, storage of data for transmission at later times in the descent, etc. Dynamic ranges of up to five decades are easily handled by the electronic processor and seven may be possible. This full range may not be available from the detector or background signals may be limiting.

Signal conditioning considerations are standard and relatively straightforward. The light source capacitor may require special consideration from a size viewpoint, but appears, at present, to be within acceptable bounds. All electronic components are commercially available and power (less than 1 watt) and size (about 100 cm^3) are easily within allowable ranges.

F. Sizes and Weight

Several configurations have been proposed during the course of this study, each of which appears to be capable of staying within allowable size constraints (i.e., less than 1500 cm^3), would weigh less than 500 grams and use less than one watt of power. There is a great deal of room for innovation here, but even straightforward design will satisfy these requirements.

III. Recommendations

A. The primary objectives stated in Section 1 can be accomplished by this experiment. Fundamental consideration in the measurements should be reliability in satisfying these primary objectives.

B. It is recommended that the system utilize:

1. A single source wavelength.

2. A backscattering configuration using,

3. Refractive collecting optics,

4. A solid state pulsed light source and photomultiplier or solid state detectors (depending on commercial availability) operating in conjunction with,

5. An interference filter set at the source wavelength,

6. An interference filter and detector set at the Hg I 2537 Å wavelength for the bright side planetary probe.

24. (Cont'd)

M. Probe Mass Spectrometer Inlet System and Interface

RESPONSE: 4-24-72

The availability of a suitable inlet system for the mass spectrometer on the large probe is considered to be a critical element in the 1976/77 multiprobe mission. ARC is forming an inlet development study team, consisting of specialists in fluid mechanics, surface chemistry and mass spectrometry and probe system engineers, to define the inlet problem, survey the current state of the art, and explore solutions. Determining the actual point of interface between project-furnished probe system and experimenter furnished mass spectrometer will largely be based on the outcome of this study. Promising inlet configurations will be modeled and tested to verify performance. Target date for preliminary report is 15 July 1972.

RESPONSE: 6-5-72

The Project Office regards the NMS as the major instrument development task for the probe missions. Consequently, heavy emphasis has been placed on exploring alternatives for inlet design and integration. The report entitled, "Probe Neutral Mass Spectrometer Inlet Design Survey," for a summary of the project's findings and plans for this area.

PROBE NEUTRAL MASS SPECTROMETER
INLET DESIGN SURVEY

A major function of the Pioneer Venus large probe is to make in-situ measurements of the Venus atmospheric compositon from an attitude of approximately 70 km to the surface. The expected minimal temperature and pressure range during this altitude interval will vary from 10 millibars to 95 bars and -30°C to 500°C respectively. Also, the Venus clouds are predicted to contain dust particles, aerosoles and vapors. These atmospheric characteristics, as would be expected, impose severe problems in the design of an inlet system for the mass spectrometer.

Preliminary design requirements for the inlet system were generated and several design approaches were formulated. These requirements and approaches are discussed in Appendix A.

These design approaches were discussed with the individuals identified in Appendix B. Their remarks are reflected in the discussion of each of the proposed systems.

The major conclusions resulting from this survey are as follows:

a. High pressure (above 1 bar) sampling of gases directly into a mass spectrometer has not been reported to date.

b. The technology presently exists to develop any of the proposed inlet systems.

c. The inlet design effort can not be separated from the pressure vessel design effort or the mass spectrometer analyzer design effort.

Due to the critical nature of the problem, the Pioneer Venus project is planning to issue an RFP (Request for Proposal) for the preliminary design of an inlet system. It is hoped that funding will permit more than one study. It is planned that this study be completed just prior to the receipt of the experiment proposals for the mission (mid October 1972).

APPENDIX A

The basic design requirements for the inlet system are as follows:

1. The gas sample must be unaltered by the inlet system. This requires that the following condiditons must be considered:

   (a) The gas should not "condense" or have molecular attachment to the walls of the inlet system.

   (b) Chemical reactions between the gas sample and the materials used in the inlet should be minimized. This includes surface reactions.

   (c) All leaks used should not exhibit any molecular selectivity for the mass range to be detected.

   (d) Operation of any inlet system components should not introduce any unknown quantities of gases into the system.

2. The entrance to the inlet system should consider the following conditions:

   (a) The sample taken should be outside of the spacecraft boundary layer.

   (b) The inlet system should not be clogged by any of the following sources of contamination:

      Atmospheric dust

      Atmospheric Aerosol droplets

      Flaking from the spacecraft insulation

The brief descriptions of the proposed systems have taken into consideration these problems and therefore have several common features that are not shown. These are as follows:

1. Each inlet system will probably have to be heated to a temperature above (how much, is a matter to be determined), the ambient. The power required for this heating has not been determined for each system.

2. The use of a chemical absorbent in the ballast volumes had been considered. This has been dropped from further consideration due to the possible buildup of the trace gases that could back flow into the sample volume and thus give erroneous readings.

3. Some sort of inflight calibration would probably be desirable. The exact method to accomplish this has not been defined.

4. All the proposed systems are based on providing sufficient mass flow to the analyzer to detect the minimum level of sensitivity required, (i.e., a minimum mass flow is required for a given level of sensitivity of the detector).

It will be noted that only brief descriptions of the proposed systems are given. More detail information is available on most of these systems. This information can be provided if required to answer any specific question on the merits of any system.

The batch sample, multiple tube, inlet system utilizes a number of individual tube assemblies that are connected to a common sample volume that, in turn, is connected to the ion source inlet.

A schematic representation of this system is shown in figure 1.

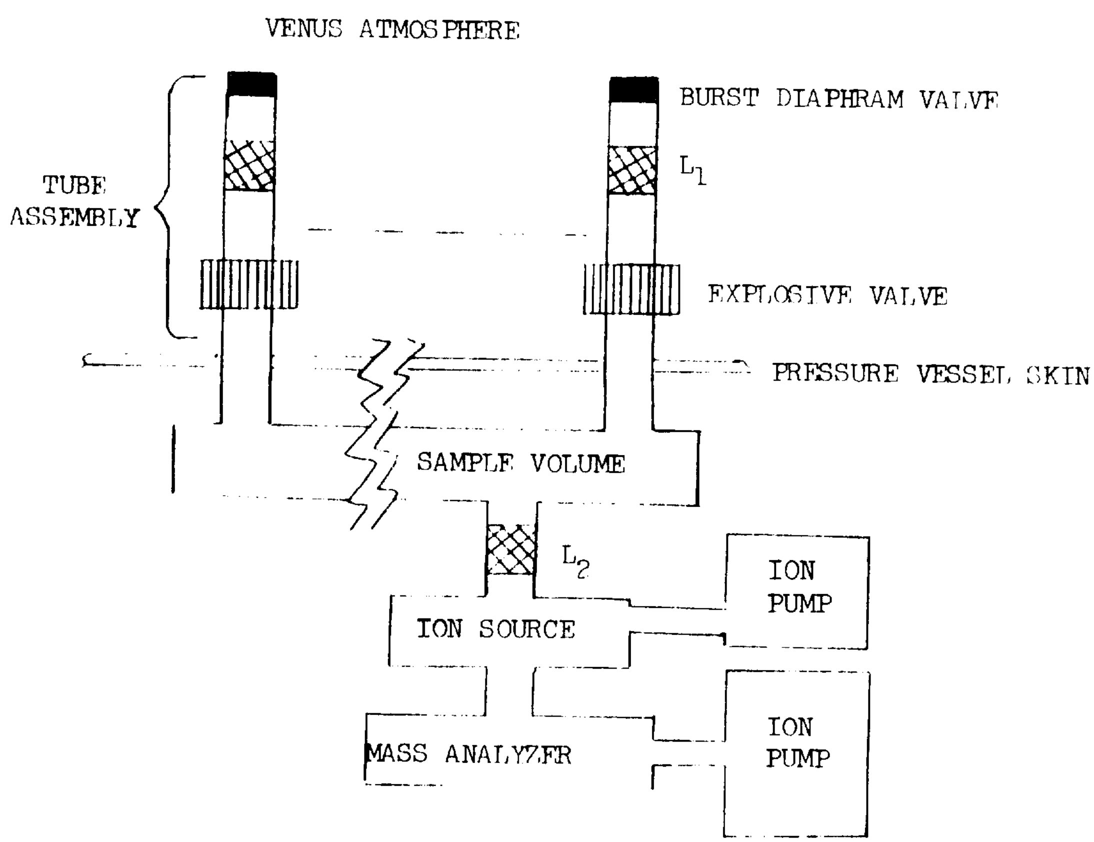


FIGURE 1.

Batch Sample, Multiple Tube Inlet System

Each tube assembly would have a burst diaphram valve that would be designed to rupture at some preset pressure differential between the Venus atmosphere and the sample volume. When a diaphram ruptured, the gas flow into the system would be limited by the inside diameter of the molecular leak. Gas flow would continue until a sensor (possibly the ion source itself) detected some maximum parameter. This sensor would then trigger the explosive valve that collapses (and seals) the inlet tube. This process is repeated until all of the tube assemblies have been activated.

System Advantages

1. Each tube diameter and molecular leak can probably be matched to permit the same total mass to be introduced in the sample volume for each gas sample taken.

2. The atmospheric pressure at the time the sample was gathered would also be known since the burst diaphram valves would be pre-calibrated.

System Disadvantages

1. The failure of one explosive valve would cause the "flooding" of the system. This problem could be alleviated with redundant valves on each tube assembly. This, of course, would require more power and weight.

2. Sample can only be obtained over the pre-selected range of burst diaphram valves.

3. Burst diaphram valves designed to burst at less than 1 bar must be adequately protected during pre launch and launch activities.

Comments

1. Why use something as complex as the ion source to generate a signal to the explosive valves? No answer is suggested for this question.

2. Are there any gases released from the tube assembly into the sample volume when the tube is collapsed?

3. It appears that as an analysis is being obtained the pressure in the sample volume will be constantly decreasing. This will cause a constantly decreasing mass flow through the ion source and thus a decreasing number of ions available for detection. Thus, the number of ionized molecules of a particular mass number present in the analyzer would vary as a function of time.

4. The ion pump, downstream of the mass analyzer is the only method of clearing the sample volume between samples. This possibly will create some problems.

The batch sample, cyclic valve, inlet system is schematically shown in figure 1.

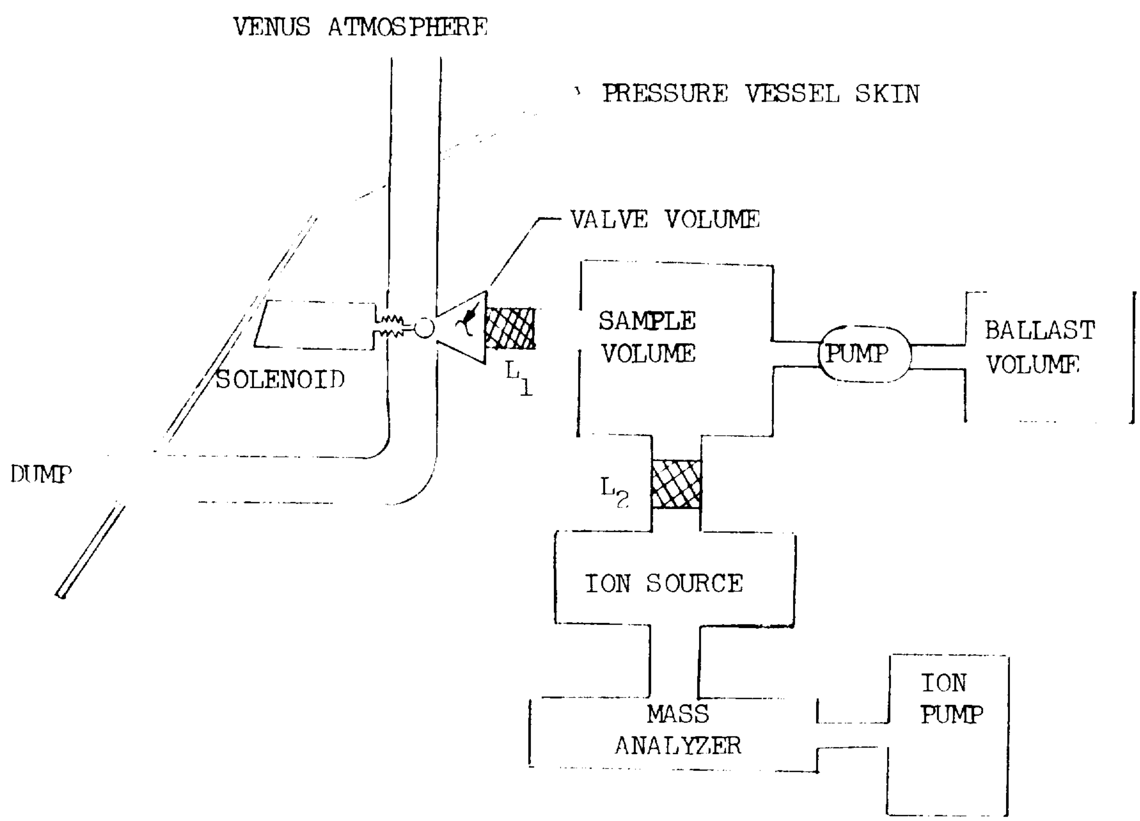


Figure 1. Batch Sample, Cyclic Valve Inlet System.

In this system the ambient atmospheric gas is bled by a solenoid operated inlet valve. This valve, when activated by a command pulse, will allow the gas to fill the valve volume. The valve will remain open long enough to assure equilibrium between the flowing gas and the gas in the valve volume. A molecular leak between the valve volume. A molecular leak between the valve volume and the sample volume will prevent "flooding" of the system during the period of valve opening. After the valve closes, its low leak rate will limit dilution of gas sample. The gas sample then "leaks" into the sample volume. The sample volume is maintained at a constant pressure by a pumping system. This constant pressure and a second molecular leak between the sample volume and the ion source provides a constant mass flow through the ion source for the duration of the analysis period.

System Advantages

1. The total number of samples that will be obtained and analyzed is only limited by the operational life of the analyzer.

2. The ion source (and thus the mass analyzer) will be exposed to a constant mass flow during the analysis period (Note: After the analysis has been completed, the pumping system will "clear" the sample volume of all residual gas before the next sample is taken.

System Disadvantages

1. A dust particle on the valve seat would probably cause excessive leakage.

2. The mass of each sample will vary due to the fixed valve volume.

Comments

1. The solenoid valve leak rate requirements (at the anticipated pressures and temperatures) are possibly beyond the present state-of-art.

2. The leak between the valve volume and the sample volume probably can not be designed to provide molecular flow for the entire pressure range to be sampled. This may require the use of a multiple valve/leak design.

3. A special pump (mechanical) would have to be developed for the system.

The constant flow, pump system is shown schematically in figure 1.

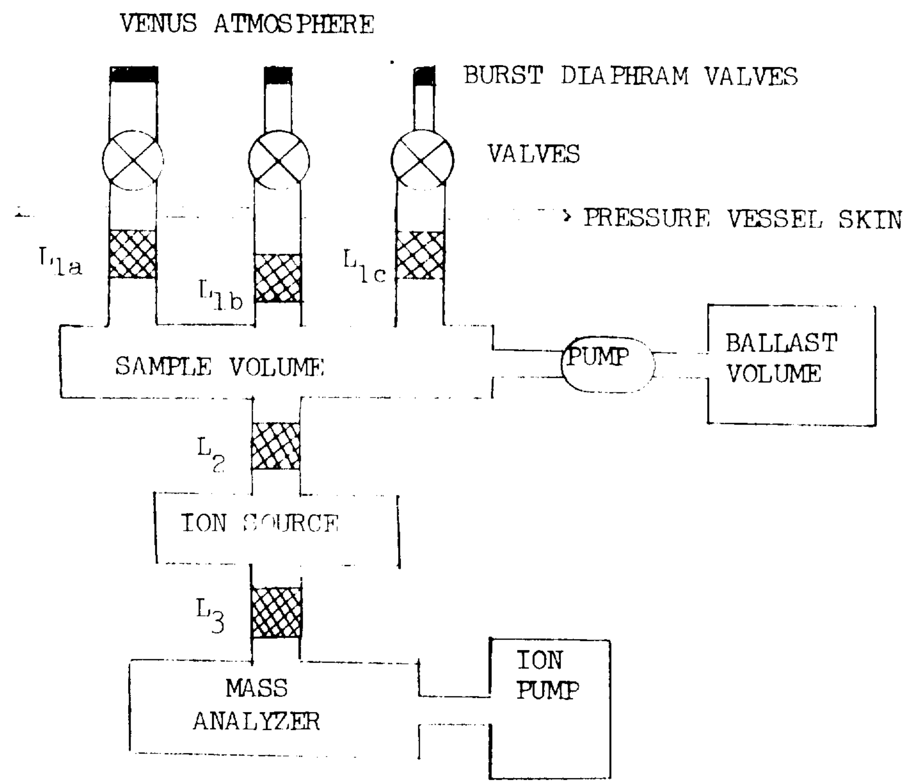


Figure 1. Constant Flow, Pump, Inlet System

This system utilizes pre-set burst diaphram valves and shut off valves to assure that there is always molecular flow into the sample volume. The sample volume is kept at a constant pressure by the pumping system. The leak into the ion source assures a constant (or nearly so) mass flow into the ion source during the period of analysis.

System Advantages

1. The total number of samples that can be analyzed is only limited by the characteristics of the inlet leaks and the capacity of the ballast volume.

2. The ion source would be exposed to a constant mass flow during the analysis period.

System Disadvantages

1. Failure of any of the shutoff valves would probably cause failure of the entire system. Redundant valves would probably be required.

2. A special pump (mechanical) would have to be developed for the system.

3. Burst diaphram valves designed to burst at less than 1 bar must be adequately protected during pre launch and launch activities.

Comments

1. The type of shutoff valve used would be a critical link in the reliability of the system. If tube "pinchers" are used, are there any gases released when the tube is collapsed? If regular valves are use, are they "leak proof"?

2. What is used to sense the pressure limit to shut off one inlet tube just prior to the rupture of the next one?

The constant flow, non pumping, inlet system is shown in figure 1.

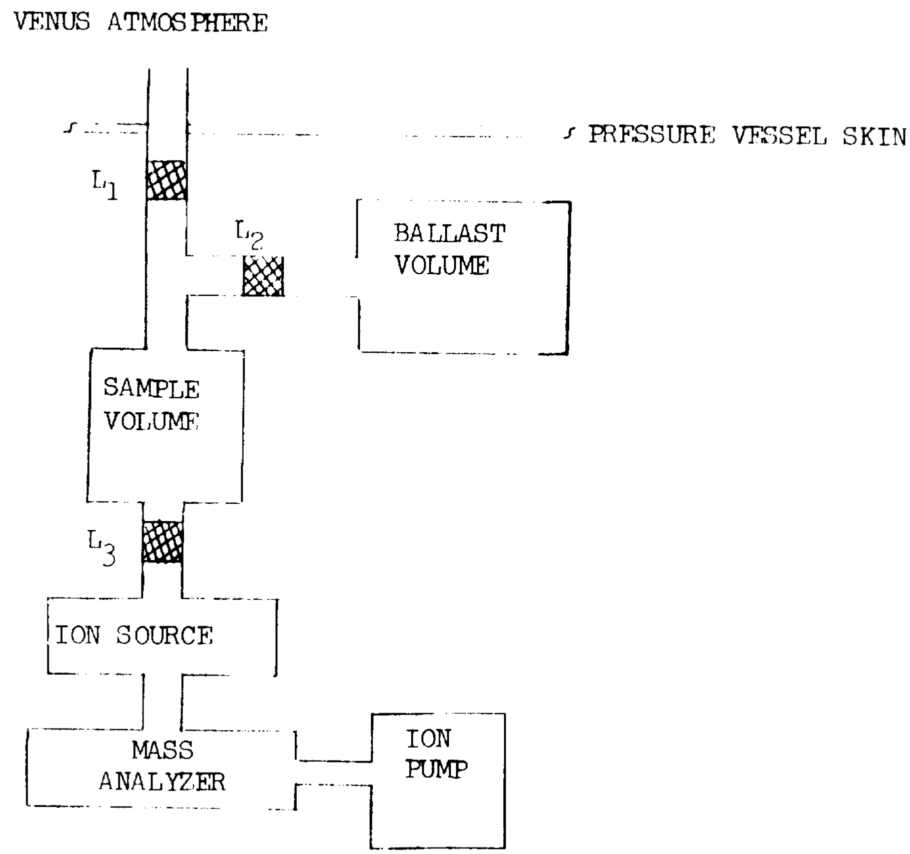


Figure 1. Constant Flow, Non Pumping, Inlet System

In this system the atmospheric gas is bled through a leak into the sample volume. A second leak into the ballast volume maintains the required pressure in the sample volume. A third leak provides a constant mass flow into the ion source.

System Advantages

1. No mechanical pumping devices required.
2. The maximum number of samples that can be analyzed is only limited by the size of the ballast volume which controls the size of the ballast volume which controls the pressure in the sample volume.
3. A constant mass flow is provided to the ion source.

System Disadvantages

1. The first leak probably cannot provide molecular flow over the entire pressure range to be sampled. This would require a multiple valve and leak arrangement.

The differential pumping inlet system shown in figure 1 has been used to sample gases at approximately 1 bar directly into the mass spectrometer. This system as shown in figure 1:

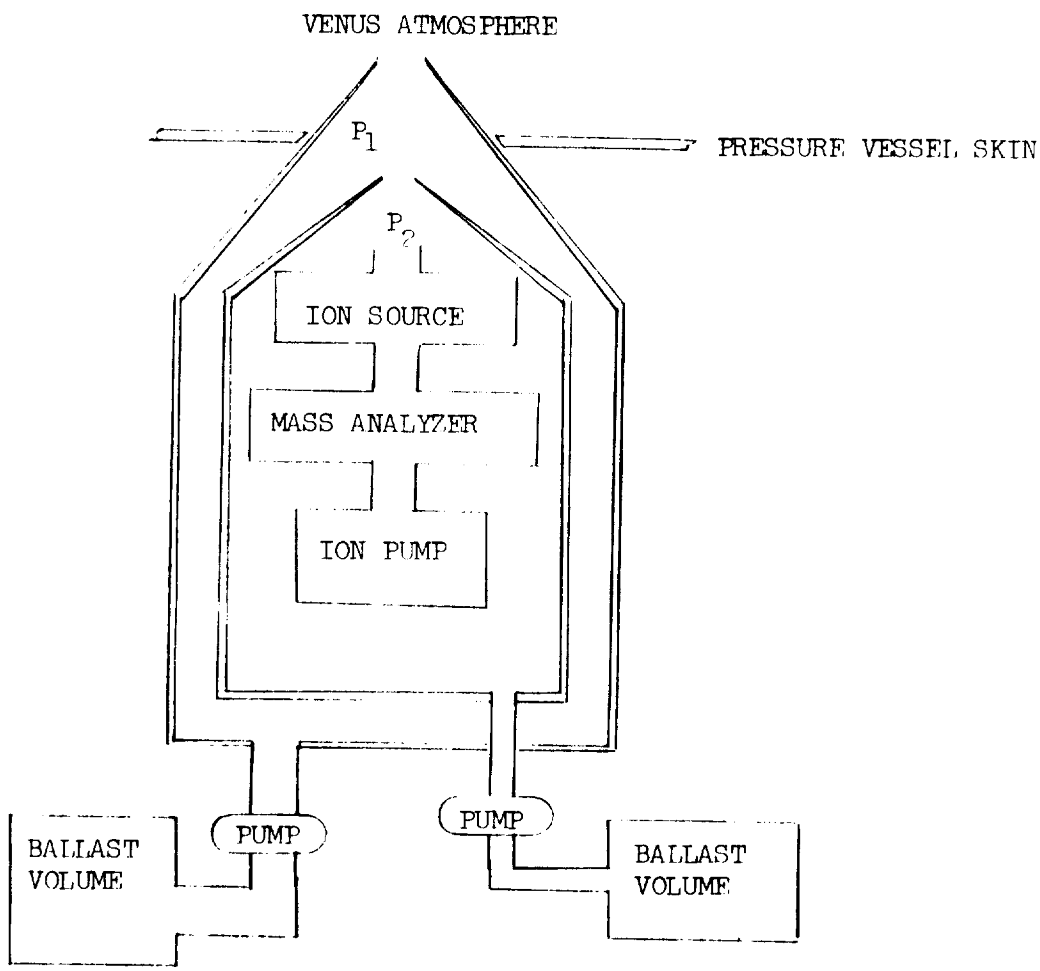


Figure 1. Differential Pumping Inlet System

In this system the gas sample goes through two expansions before it reaches the inlet to the ion source.

System Advantages

1. There is an absolute minimum of wall collisions of the gas sample from the time it enters the system to the ion source.

System Disadvantages

1. High power requirements for pumps to operate at high ambient inlet pressures.

Comments

1. This system probably could not operate at pressures much above 1 bar without some sort of multiple or variable inlet orfice system.

Two systems were proposed to remove CO_2 before it entered the mass analyzer. Both of these systems only consider the gas sample after it has been obtained in a "sample volume."

The first system is a chemical absorber that would selectively absorb the CO_2. This approach is shown in figure 1. The main problem to this approach is assuring that the absorber is highly selective to CO_2 or its selectivity for other compounds is well known.

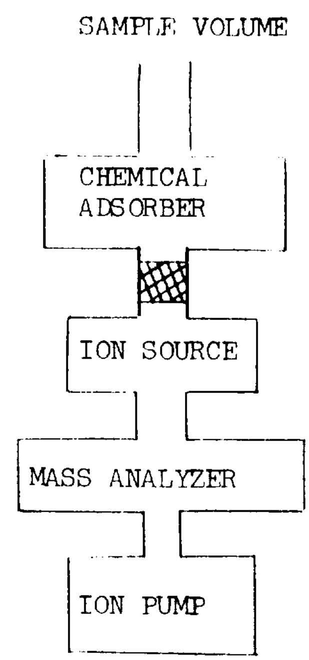


Figure 1. Chemical Absorber Inlet System

The second proposed system utilizes a "coarse" mass spectrometer to remove the CO_2 as ions. The main disadvantage to this system is the additional power and weight required to remove a significant number of CO_2 ions. This system is shown in figure 2.

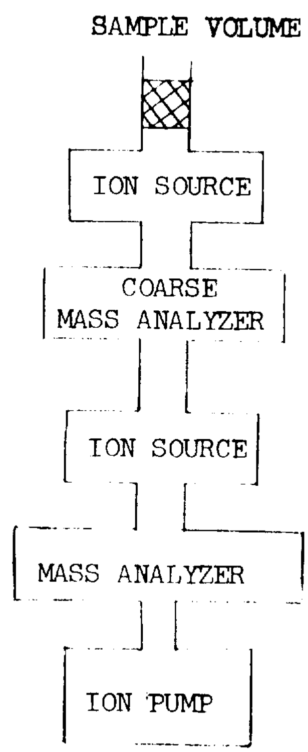


Figure 2. Ion Removal Inlet System

APPENDIX B

CONTACTS MADE

Varian Associates
Palo Alto, California
Mr. Tom Snouse
Subject: High vacuum pumping technology

Aero Vac (Subsiderary of High Voltage Engineering)
Burlington, Massachussetts
Dr. David Holkeboer
Subject: High vacuum pumping technology

Analog Technology Inc.
Pasadena, California
Dr. Wilson Brubaker
Subject: Mass Spectrometer inlet design critique and high vacuum pumping technology

Perkin Elmer Corporation
Aerospace Division
Pomona, California
Mr. W. C. Qua
Subject: Mass Spectrometer inlet design critique

Westinghouse Research Labs
Pittsburgh, Pennsylvania
Mr. William M. Hickam
Subject: Mass Spectrometer inlet design critique

Jet Propulsion Laboratory
Pasadena, California

Mr. Charles Giffin
Mr. Len Sieradski
Dr. Lenord D. Jaffee
Subject: Mass Spectrometer Inlet design

Rensselaer Polytechnic Institute
Troy, New York
Dr. Fredrick A. White
Subject: Mass Spectrometer Inlet Design

California Institute of Technology
Pasadena, California
Dr. Gerald Wasserburg
Subject: Mass Spectrometer Inlet Design

Bendix Aerospace
Ann Arbor, Michigan
Dr. Richard Liete
Subject: Mass Spectrometer Inlet Design

Attempted to contact but could not reach the following individuals to discuss the Mass Spectrometer Inlet Design:

Dr. Al Nier
University of Minnesota

Dr. John Robo[illegible]
Mt. Sinai Hospital
New York City, New York

Other Suggested Contacts:

Bendix Corporation
Ann Arbor, Michigan
Mr. Lowell Furgeson
Dr. John Carrico
Mr. Edwin Shaefer
Mr. Niel Thomas

NASA Personnel involved in the inlet design task:

Dr. Dale Compton
Mr. Walter Starr
Dr. James Pollock
Mr. Lou Polaski
Mr. Tom Canning
Mr. Dean Chisel
Mr. Charles De Rose

25. The Pioneer Venus Project will determine what materials are available for IR (10μ) windows that will not degrade in the Venus temperature, pressure and chemical environment.

RESPONSE:

Inquiry at Ames has yielded no candidates for IR windows for use on descent probes with extremely high transmission at 10μ. In order that reasonably good radiometry be done, a strong window (reasonably thick) would influence the measurements strongly. In order to perform good quantitative radiometry recourse to auxilliary apparatus such as an external chopper wheel would be required. The chopper would have a known, i.e., measured, temperature and would present in sequence a distant view, a "black" surface for a known reference field, and a reflective surface to yield a measurement of the window's signal contribution. Synchronous, phase controlled detection would be required to make sense of the resulting signal.

26. The Pioneer Project is to determine the feasibility of having a meeting between potential Phase B contractor and selected SSG members to exchange technical information.

RESPONSE: 6-5-72

The Pioneer Venus Project has transmitted a request to the Phase B Source Evaluation Board Chairman asking that if legal, this meeting be allowed. His response, based on an interview with the NASA/ARC procurement legal staff, indicated the subject meeting could not be initiated by the Project Office nor by the Source Evaluation Board unless directed to do so by Dr. Naugle, NASA Associate Administrator for Space Science. This result has been passed on to Mr. Dan Herman, Advanced Planetary Programs Manager, OSS, for coordination.

The best time for the Project for this meeting would be before July 1972, if desirable to review the information with all three contract teams, or after July 1972, if the meeting is for the two Phase B contractors. The NASA Administrator will make his selection late in July 1972.

Mr. D. Herman (Washingington/Hqrs.) is to generate a letter to ARC requesting that a meeting between the potential pahse B Contractors andselected SSG members be held.

27. NASA Headquarters is to formally request the Pioneer Venus Project to prepare a revised description of the orbiter based on the Phase B proposals by July 1, 1972.

RESPONSE: 6-5-72

NASA/Headquarters has directed the Pioneer Venus Study Team to investigate the aspects of possible ESRO participation in the orbiter mission. Based on tentative agreements made relative to this interface, ESRO will direct their present study efforts toward this possible cooperation. This, plus the requirement for a spacecraft definition for the forecoming AFO issuance, has established a need for a baseline document.

The legality of preparing a document of this type at this time has been questioned because of the Phase B Source Evaluation Board activities. The Phase A document generated by NASA/GSFC is not applicable because of the significant changes that have occurred in the mission concept since that document was written. An example of this has been the increased size of the Delta Launch Vehicle shroud.

An agreement has been reached, however, which has been agreed to by all parties concerned. The subject baseline document will be prepared and treated as priority information. Following a successful presentation to the NASA Administrator by the Source Evaluation Board on July 26, 1972, and the selection of two Phase B Contractors, the subject document will be presented to NASA Headquarters for their use. The primary use of the document will be to define the Universal Bus for ESRO and to become supporting material for the AFO.

As quickly as they are known, this document will be revised with specific details of the spacecraft system.

28. Dr. Rudolph Hanel (NASA/GSFC) is to be requested to reexamine the simple two-channel IR radiometer cloud detector for Venus.

RESPONSE: 6-5-72

Mr. Spencer reported that Dr. Hanel is interested in such a device but due to his present work load was unable to provide any reexamination of it at this time.

29. The Pioneer Venus Project will assess the problem of making Venus atmosphere measurements with the Turkevitch consortium and work with them to develop a conceptual design of a practical alpha particle device to measure the composition of condensates. The sensitivity analyses will be revised where appropriate. Drs. Hunten and Kliore will discuss the alpha particle analyzer with Franzgrate.

<u>RESPONSE</u>: 6-5-72

Adequate time was not available to complete this item. Dr. Hunten report, "Nuclear Fluorescence Experiments, a Tentative Evaluation," dated May, 1972, discusses this type of instrumentation. This report is included in the response to Action Item 24. C.

30. GSFC to provide the detail design status of their approach to the Probe neutral mass spectrometer.

<u>RESPONSE</u>: 3-29-72

During the atmospheric structure subgroup meeting, Mr. Spencer described the mass spectrometry development presently being pursued at GSFC.

<u>RESPONSE</u>: 4-24-72

Mr. Spencer reported that GSFC is building a model of their approach to the inlet design. Some test results should be available by the June SSG meeting.

<u>RESPONSE</u>: 6-5-72

Mr. Spencer reported that experiments had been conducted at GSFC that demonstrated that a porous plug leak at elevated temperatures (1000°C) could reduce the pressure from 100 atmospheres to 10^{-5} torr in one step. Several compositions of gas were used in these tests.

31. Status of requirements for temperature and pressure measurements in the lower atmosphere.
(Generated 3-29-72)

RESPONSE: 4-3-72

Letter from R. Goody to A. Seiff

RESPONSE: 4-24-72

A. Seiff distributed a report entitled "Discussion of Sensors Available for pressure and temperature measurement in the Lower Atmosphere of Venus".

RESPONSE: 6-5-72

A. Seiff gave a verbal report on his efforts in surveying existing sensors. Test data has been furnished by vendors on a number of off-the-shelf instruments and several appear suitable, with minor modifications, for the Venus Probe missions. Study of alternatives will be continued.

HARVARD UNIVERSITY
PIERCE HALL, 29 OXFORD ST.
CAMBRIDGE, MASSACHUSETTS 02138
OFFICE OF THE DIRECTOR

CENTER FOR EARTH AND PLANETARY PHYSICS

April 3, 1972

A. Seiff
NASA Ames Research Center
Moffett Field, California 94035

Dear Al,

I find myself hard pressed for time and yet I think it essential to get out preliminary specifications for the Pioneer instruments. The following thoughts on T and p are therefore preliminary, but the miniprobe group would be helped greatly if you could give them your consideration. Two weeks from now I hope to have a documented and reasoned presentation of the specifications.

First, consider the altitude range. According to Gierasch, Goody and Stone (G.F.D., 1, p. 1, 1970) radiative equilibrium will commence at 0.2 atmospheres. Also $t_s \simeq t_d$ at 1 atmosphere. This then is the division between the deep, undisturbed atmosphere, and the radiation-dominated region depending upon cloud densities, etc. It is also about the pressure of the cloud tops. Above this level temperatures can and should be measured by sounding from a satellite or balloons. 4 measurements are likely to be more affected by ephemeral changes than planetary gradients. The miniprobe group has therefore agreed that the emphasis of the miniprobe measurements should be on pressures in excess of 1 atmosphere, with emphasis on the lowest three scale heights, i.e. below 40km. Between 40 and 20 km the fall speed averages 1 km min^{-1}, and this is the general level of velocity for which the probe should be optimized. If good performance can be extended to higher velocities and pressures lower than 3 atmospheres at small cost in weight and data and without the use of a new measurement system, we would like to know.

Temperature measurement
Range 400 - 750K (possibly down to 250K)

Accuracy	Absolute	1%
	Relative between probes	0.5 K
	Sensitivity	0.1 K
	Lag*	0.5 sec

$$* \quad \text{Lag} \simeq \frac{\text{sensit.}}{w\Gamma}, \quad w = \frac{1}{60}\ \text{km sec}^{-1}, \quad \Gamma = 10.7\ K\ \text{km}^{-1} \ \text{at depth.}$$

Pressure measurement

Range 100 to 3 atm (possibly down to 1)

Accuracy*	Absolute	5%
	Relative, between probes	0.3%
	Sensitivity	Obtained from time-height
	Lag (for 0.3% accuracy)	2.5 sec.

* $\frac{\Delta p}{p} = \frac{\Delta T}{pH}$, H = 14.9 km at depth.

Please give me a call if you have any problems with these specifications.

Sincerely,

Richard

Richard Goody

cc: Miniprobe sub-committee
Fellows, Colin, Bauer, Hunten.

RG/dc

DISCUSSION OF SENSORS AVAILABLE FOR PRESSURE AND TEMPERATURE MEASUREMENT IN THE LOWER ATMOSPHERE OF VENUS

1. What are the atmospheric temperature and pressure sensors used on radiosondes and aircraft? What is their accuracy? Are they directly applicable for Pioneer Venus?

Radiosondes generally use rod thermistors as temperature-sensing elements. Thermistors are semiconductor devices with large (negative) temperature coefficients of resistance, rapid response, and limited temperature range. On one standard ESSA sonde, the temperature range is from 183 to 323° K. At higher temperatures (around 400° K), the highly nonlinear resistance function of temperature decreases to near zero, levels off, and sensitivity is lost. In the working range, accuracy quoted by the manufacturer is 0.4° C 1σ, but users (and the Meteorological Working Group of IRIG) report RMS deviations of about 1° C about the mean. These sensors are not directly applicable to the Venus lower atmosphere because of their measurement-range limitations. A preliminary opinion is that thermistors as a class are not applicable for temperatures as high as 750° K.

Temperature sensing from aircraft is generally with resistance thermometers, configured in a pitot tube with bleed holes so as to measure total temperature (ambient plus dynamic contribution). Commercially available precision sensors of this type have ranges from 200° K to 625° K, but could probably be extended readily to 800° K by selection of appropriate materials. Accuracies are not specified in simple form by the manufacturer (Rosemount Engineering). However, the sensor as received (without further calibration) has a temperature at any given resistance within 0.25° C + 0.005 T of that specified in the brochure (e.g., at 600° K, within 3.25° C). Calibration of the individual sensor should reduce this error. One example of estimated accuracy in an application involving steady flight at M = 0.8, T_t = 253° K gives an indicated probable error of 0.5° C after corrections are applied. Radiation shielding is stated to reduce radiation errors to negligible proportions. Response time of these sensors is generally slow compared to other types. However, for the lower atmosphere of Venus (p > 4 atm), this may not be important. This type of sensor is a candidate for application to Pioneer Venus. Detailed evaluation of errors under conditions of the Venus lower atmosphere is required.

Pressure sensors used on radiosondes and aircraft work in the pressure range less than 1 atmosphere, and at ambient temperatures found in the Earth's atmosphere. Typical instrument is aneroid barometer. Probable errors quoted by Meteorological Working Group of IRIG are 0.2% for p > 500 mb to 1.0% at 10 < p < 50 mb. This sensor is clearly not applicable to Venus' lower atmosphere.

2. What other sensors are developed and essentially flight ready?

Temperature. The PAET sensor is developed, flight demonstrated, and applicable. It consists of three butt-welded thermocouples in parallel (for redundancy) mounted on slender posts and exposed to the atmosphere outside the vehicle boundary layer. Chromel-alumel thermocouples have been used (working range to 1000° K), but platinum, platinum-rhodium could also be readily substituted. The aeroshell phase sensor of this type being developed for the Viking entry vehicle has a specified working range from 100° to 750° K, directly appropriate for Venus' lower atmosphere. Sensitivity of chromel-alumel thermocouples is 0.043 mv/°C, so that measurement to 0.5° C would imply electronics stable to 0.02 mv output, and a calibration procedure of highest care, as well as control of errors due to radiation (by use of highly reflecting surface finish on thermocouples) and conduction (into support posts). Periodic cold junction temperature measurement (e.g., at 60 sec intervals) to an accuracy of 0.25° C by means of a resistance thermometer in thermal contact with the cold junction would be required. Relative accuracy between sensors for different probes could be enhanced by calibrating them together in the same test environment. The response speed of these sensors has been estimated and found ample ($\tau < 0.05$ sec). A detailed computer evaluation of errors due to radiation and convection is being made at the present time. Study is also required of the electro-thermal stability for four months in the space environment, and the stability of suitable electronics. This sensor is a candidate for application to Pioneer Venus probes.

Pressure. The pressure and temperature range of the Venus lower atmosphere is well outside the capabilities of pressure sensors used in the Earth's atmosphere, but it is not outside the range of sensors used in shock tubes and in industry. A wide range of types is commercially available. Typically, these employ diaphragms which deflect under pressure. The deflection is measured by means of bonded (wire wound or film type) strain gages, unbonded strain gages, or capacitance change relative to a fixed sensing plate. An attractive type uses the force on a rigid diaphragm (with a flexible diaphragm seal around the periphery) to compress a piston on which strain gage elements are fixed (manufactured by Norwood Controls). Change in the strain gage resistance is calibrated to define the pressure.

Typical accuracy expectation is given by repeatability (0.1% of full scale), linearity within 0.5%, and thermal zero shift of 0.036%/°C. (Latter should be calibrated and corrected by means of sensor temperatures measured occasionally - e.g., at 1 min intervals or longer in flight.) Working temperature range is 220° to 420° K. Hence, gage requires a moderate temperature environment, and must not be heated outside this range by the gases admitted. (The quantity of gas admitted is small, and its heat should be readily absorbed by the entrance tubing.) These and similar sensors are commercially available at modest cost. Flight qualification, for vibration, etc., is required, but it does not appear to pose difficulties.

Recommendation: Project should acquire selected types, and evaluate ability to withstand flight qualification and other environments without loss in accuracy.

3. What reading rates and data rates are required?

Descent velocities in the lower 40 km are in the range 25 to 4 m/sec (decreasing with altitude). Temperature readings accurate to 0.4° C are provided by 11 bits with a full range of 800° K, while 12-bit words will give pressure readings accurate to 0.25% at 1/10 of full range pressure (30 km altitude), and readings accurate to 0.7% at 1/25 full range pressure (40 km altitude). If we allow 2 additional bits/reading for intermittent transmission of supplementary data, such as cold junction temperature readings, sensor and pressure electronics temperatures and excitation voltages, etc., the total data requirement per p,T reading is 27 bits. If these readings occur at 14 second intervals, the bit rate is 2 sec^{-1}, and the altitude resolution is 340 meters initially, 55 to 135 meters near the surface. A somewhat lower reading rate than this would probably also be acceptable, with somewhat reduced altitude resolution.

4. What are representative instrument weight and power requirements?

a. Temperature sensors. PAET/Viking type. Weight, 1 lb (includes housing, deployment mechanism, and electronics). Power requirement, less than 1 watt, (4 mw directly consumed).

Platinum resistance thermometer (Rosemount Engineering model 101F). Weight, 7 oz (not including deployment mechanism or electronics). Power requirement, less than 1 watt, (4 mw directly consumed).

b. Pressure sensors. Weight, 4 to 8 oz, not including inlet tubing or signal amplifier (if needed). Power, < 1 w (0.3 w directly consumed in sensor).

5. Interfaces with probe systems.

a. Main probe.

(1) Temperature sensor.

Mounted external to descent capsule. Exposed on parachute deployment when heat shield is jettisoned. (No deployment mechanism.) Requires electronic connections through pressure shell. Requires region of stable temperature for cold junction if thermocouple is employed as sensor. Requires 5 to 10 v DC power source, and produces a "low level" (0-40 mv) signal output.

(2) Pressure sensor.

Mounts internal to descent capsule with pressure port through shell. Reads on jettisoning of the heat shield, or earlier if a porting arrangement is provided. Sensor requires region of stable, moderate temperature (preferably < 100° C), and an inlet heat exchanger (perhaps a thick-walled copper inlet tube will suffice) to reduce the temperature of the gas which enters the sensor. Requires 10 v DC excitation source and produces a "low level" (0-40 mv) signal output.

b. Miniprobes.

Interfaces are same as for main probe, except that deployment of the temperature sensor through the heat shield is required when Mach number comes below ~2, if the design is such that the heat shield is retained. Also, the ablation material must be such that it does not plug the pressure orifice.

A. Seiff

Alvin Seiff

April 20, 1972

6. Magnetometer

Venus: Strategy for Exploration states that "high priority is contingent upon further feasibility studies." These studies have still to be made and consequently the rationalization for this instrument is well behind other parts of the mission.

Scientific questions:

Under what conditions can data be analyzed in terms of internal magnetic fields?

What conditions must be placed upon the space craft and the flight path?

Must the instrument transmit from the ground?

Can it operate from a magnetic space craft?

Weight, power, data rate?

Action: Chris Russell to produce a paper and obtain reviews from Don Anderson and George Wetherill.

RG/dc/3-20-72.

32. Prepare a detailed outline of the SSG final report.

RESPONSE: 3-29-72

L. Colin distributed a preliminary outline.

RESPONSE: 6-5-72

L. Colin distributed a detailed outline.

Rec'd 3-29-72

SCIENCE STEERING GROUP FINAL REPORT CONTENTS

- SCIENTIFIC OBJECTIVES REVISED
    - OVERALL PROGRAM
    - BUS, LARGE PROBES, SMALL PROBES, ORBITER, '80 MISSION
- SCIENTIFIC MEASURABLES - 76/77 MISSION
    - PARAMETERS VS. ALTITUDE REGIME, SAMPLING FREQUENCY, RANGE, ACCURACY, RESOLUTION, ETC.
- CANDIDATE PAYLOADS - 76/77 MISSION
    - NOMINAL
    - NOMINAL ± REASONABLE Δ's
- CRITICAL INSTRUMENT DEVELOPMENT/TESTS - REQUIREMENTS - 76/77 MISSION
    - ESSENTIAL INSTRUMENTS
    - ALTERNATIVE CONCEPTS
- TARGETING STRATEGIES - 76/77 MISSION
- 1978, 1980 MISSIONS - PRELIMINARY STATEMENTS ON MEASURABLES, CANDIDATE PAYLOADS, TARGETING

PIONEER VENUS SCIENCE STEERING GROUP

Final Report Outline

Foreward — R. Fellows, L. Colin, S. Bauer

a. Planetary Explorer Project History - 1965 thru 1971 (GSFC)
b. Pioneer Venus Project Plan - 1972 thru 1982 (ARC)
c. SSG Goals and Objectives
d. Final Report layout and limitations

Chapter I - Why Explore Venus Now?

a. A June 1972 critique of the June 1970 SSB Study - R. Goody
b. First-Order questions about Venus
c. Soviet Accomplishments and Future Predictions
d. The low-cost Pioneer Venus concept
e. Achieving cost constraint and credibility
f. Instrument feasibility
g. Proposed missions sequence

Chapter II - The 1976/1977 Dual Launch, Multiple Probe Mission

I. General Mission Description and S/C Constraints - R. Jackson

II. Large Probe - D. Hunten

a. Scientific Objectives
b. Scientific Measurables
c. Candidate Payloads
d. Targeting Strategies

III. Small Probes - R. Goody

a. Scientific Objectives
b. Scientific Measurables
c. Candidate Payloads
d. Targeting Strategies

IV. Bus ~~A. Nagy~~ C. Russell

a. Scientific Objectives
b. Scientific Measurables
c. Candidate Payloads
d. Targeting Strategies

V. Critical Instrument Development - J. Sperans

a. Recommended long-lead study items
b. Status
c. Project-supplied instruments
d. Cost constraint and credibility
e. Parallel developments

Final Report Outline (Cont'd)

Chapter III - The 1978 Orbiter Mission

I. General Mission Description and Spacecraft Constraints - R. Jackson

II. Orbiter - ~~C. Russell~~ A. Nagy

a. Scientific Objectives
b. Scientific Measurables
c. Candidate Payloads
d. Targeting Strategies

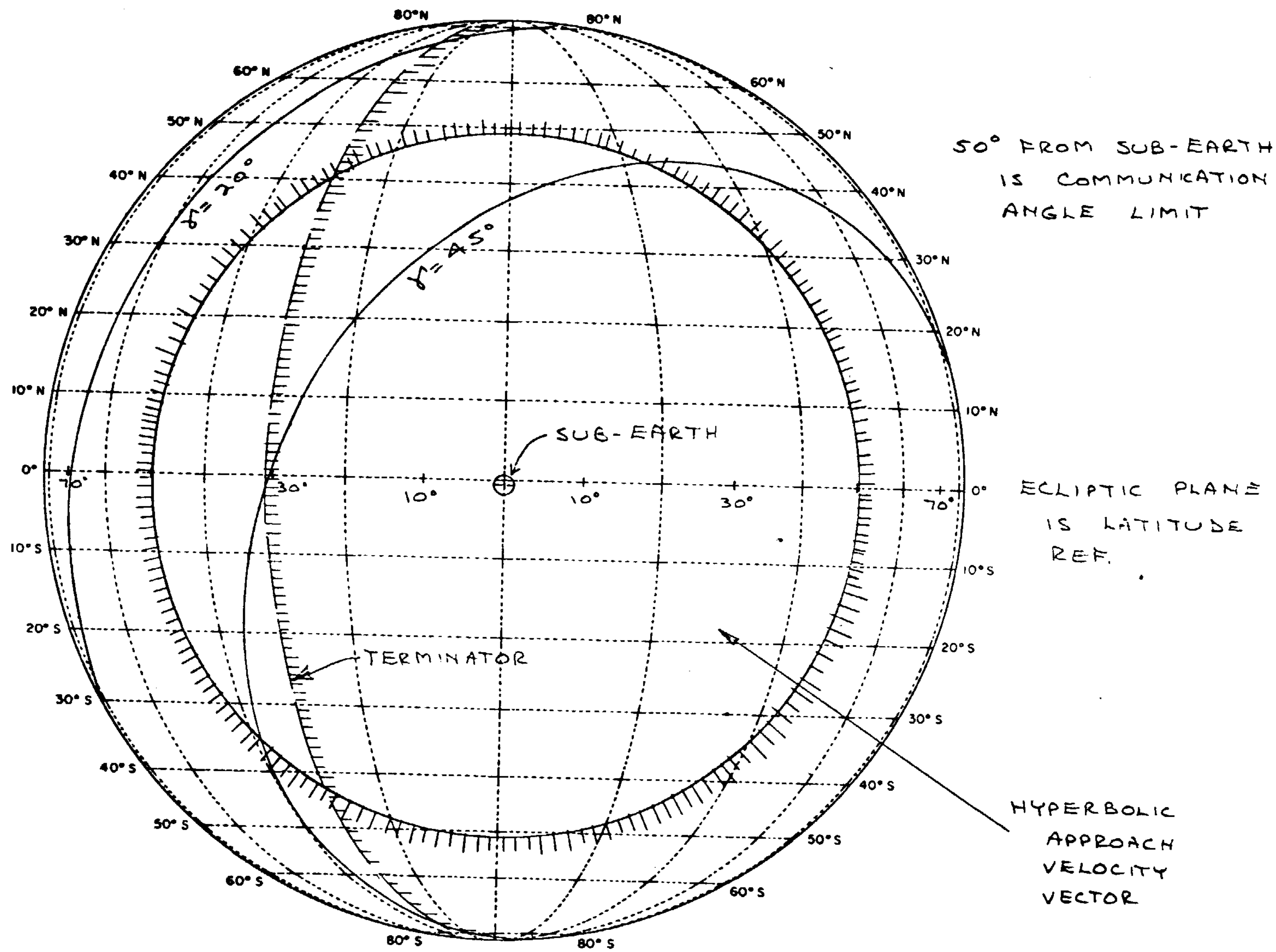
Chapter IV - The 1980 Mission

Appendix - SSG Participants List

33. Define the targeting constraints for the large and small probes.

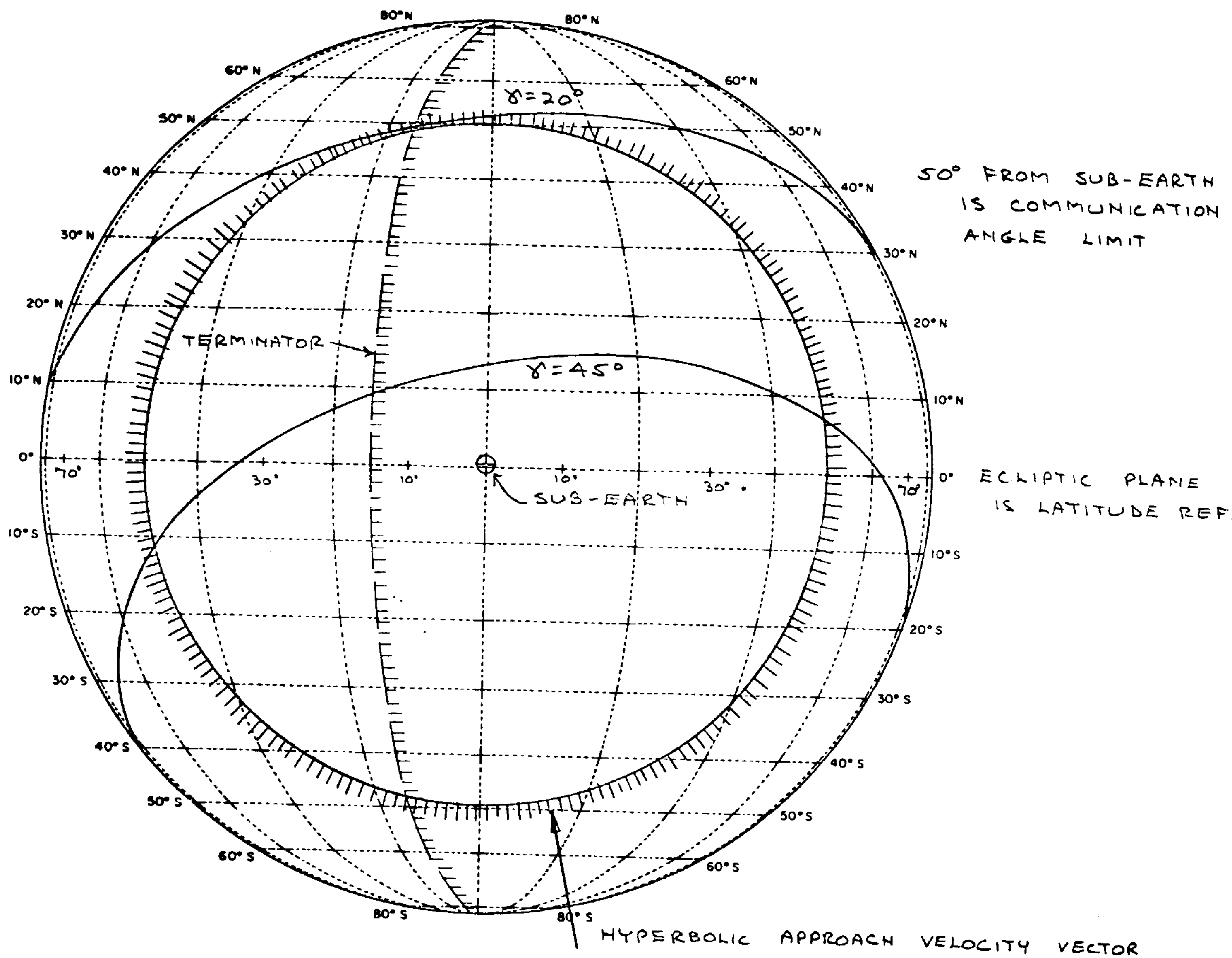
RESPONSE: 3-29-72

R. Jackson gave a verbal report on this subject. The charts used for this presentation are attached.



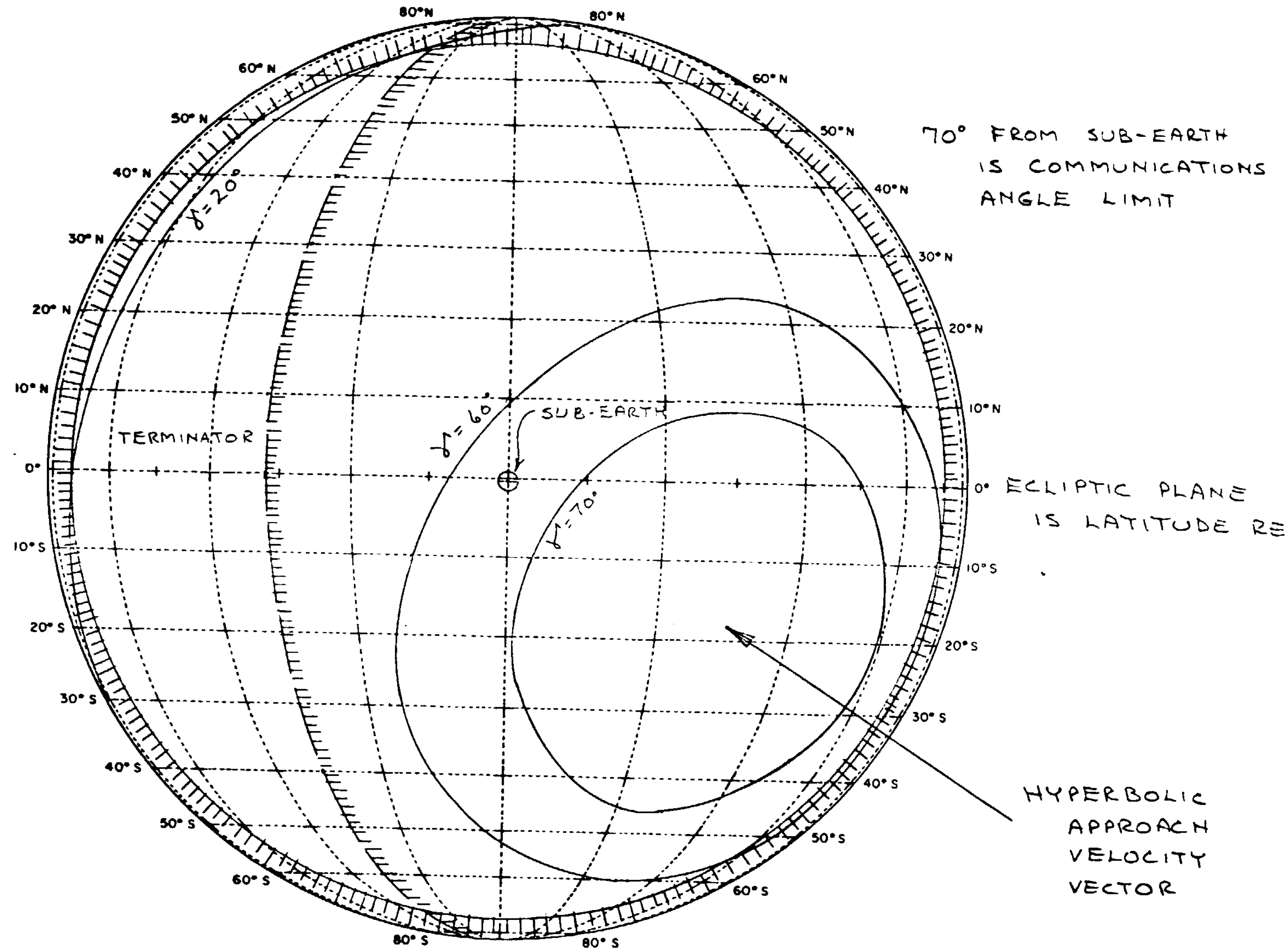
LARGE PROBE TARGET AREAS - FIRST MISSION

LAUNCH JAN 10, 1977, ARRIVE MAY 8, 1977
TARGET AREAS ARE AT 150 KM ALTITUDE
VIEW FROM SUB-EARTH LONGITUDE



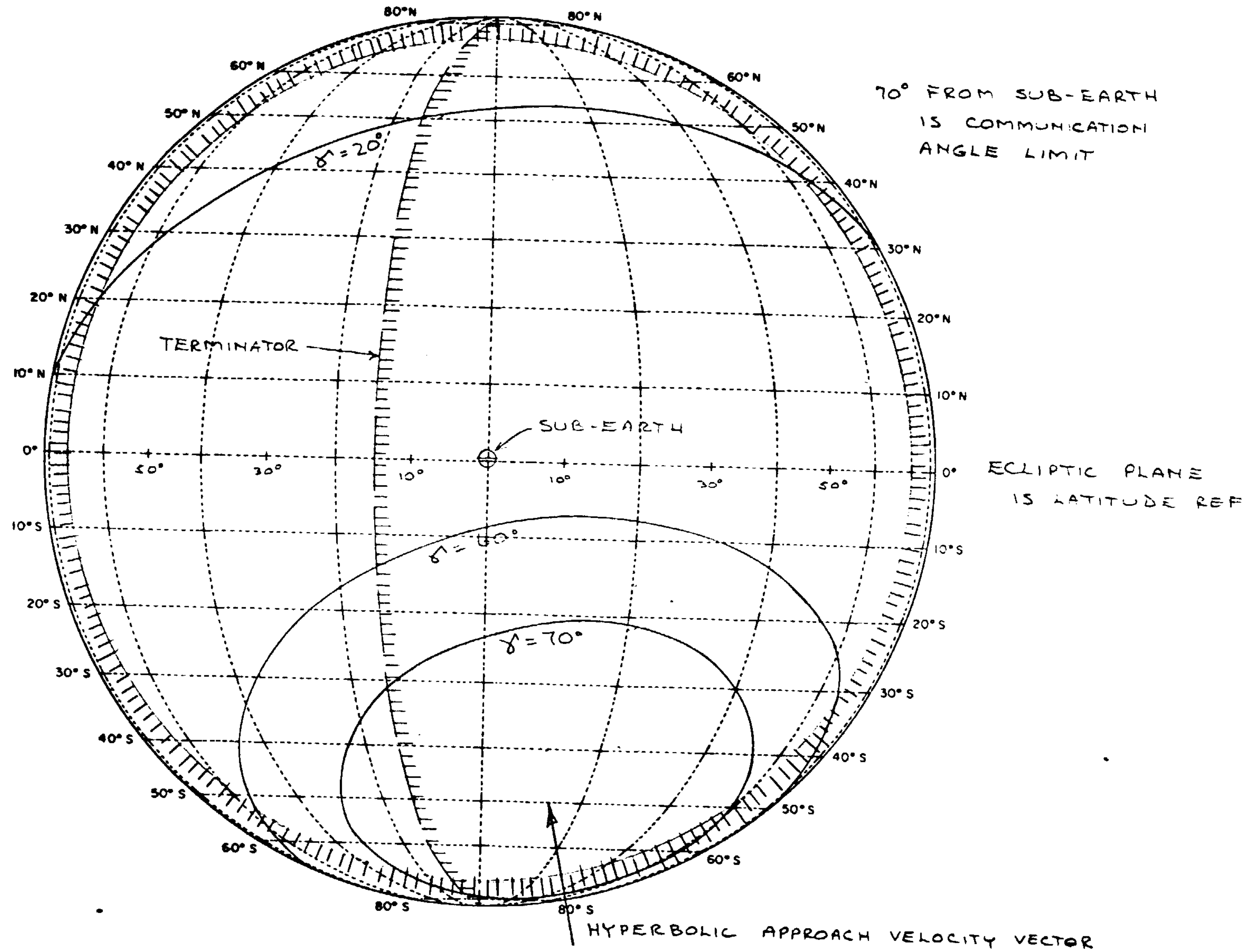
LARGE PROBE TARGET AREAS SECOND MISSION

LAUNCH JAN 17, 1977, ARRIVE MAY 25, 1977
TARGET AREAS ARE AT 150 KM ALTITUDE
VIEW FROM SUB-EARTH LONGITUDE



SMALL PROBE TARGET AREAS FIRST MISSION

LAUNCH JAN 10, 1977, ARRIVE MAY 8, 1977
TARGET AREAS ARE AT 150 KM ALTITUDE
VIEW FROM SUB-EARTH LONGITUDE



SMALL PROBE TARGET AREAS SECOND MISSION

LAUNCH JAN 17, 1977, ARRIVE MAY 25, 1977
TARGET AREAS AT 150 KM ALTITUDE
VIEW FROM SUB-EARTH LONGITUDE

HARVARD UNIVERSITY
DIVISION OF ENGINEERING AND APPLIED PHYSICS

R. M. Goody,
Mallinckrodt Professor
of Planetary Physics

Pierce Hall
Cambridge, Massachusetts 02138

March 20, 1972

Dr. Lawrence Colin
NASA
Ames Research Center
Moffett Field, California

Dear Larry:

The enclosed paper suggests quite a few tasks for the Project Office.

With regard to the temperature and pressure gauges, I was looking for a definition of time-height-temperature-pressure for possible mini-probe configurations. I think all members of the sub-committee would welcome this information.

All other references to the Project Office should be relatively easy to understand.

I also suggest that someone at Ames starts looking at the heated optical window problem, because it will keep cropping up.

Sincerely,

Richard

Richard Goody

RG/eh
enclosure

HARVARD UNIVERSITY
DIVISION OF ENGINEERING AND APPLIED PHYSICS

R. M. GOODY,
Mallinckrodt Professor
of Planetary Physics

Pierce Hall
Cambridge, Massachusetts 02138

March 20, 1972

To : Members of the Miniprobe sub-committee
Robert Fellows, Lawrence Colin, Siegfried Bauer, Al Sieff.

From: Richard Goody

I enclose an attempt to define the scope of problems involved with the miniprobe with indications of who might do something to clarify them. Please do what you can before the Ames meeting.

Venus Pioneer SSG

Sub-committee on Miniprobes.

Membership

Richard Goody, Chairman
Harvard University
Pierce Hall, 29 Oxford Street
Cambridge, Massachusetts 02138

Jacques Blamont
CNES 129 Rue de l'Universite
Paris 7, FRANCE

Arvydas Kliore
Jet Propulsion Laboratory
Pasadena, California 91103

Gordon Pettengill
Dept Earth & Planetary Sciences
Rm 54-612
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Christopher Russell
Institute of Geophysics & Planetary Physics
University of California
Los Angeles, California 90024

General Questions

1. Probe locations

Where are the desirable probe locations (a) for the first mission? (b) for the second? The sub-committee could address itself to certain general questions but the optimum choice of probe locations depends upon more knowledge of the entry and communications problems, and the estimated cost to other parts of the mission. General questions are: Need the probes be placed in two hemispheres, or is one sufficient? What is the minimum acceptable spread in latitude (e.g. 45^{o})? What is the maximum spread for which signficant cost need be paid (e.g. 60^{o})? How many should be on the day side?

Action: Sub-committee discussion.

2. Communications

Planning for the miniprobes is most sensitive to the communications problem. Has this been studied in sufficient depth for the SSG to reach satisfactory conclusions? Enough questions have been raised, particularly about the effect of turbulence, to suggest that we should take a very conservative view.

Action: Ames Project Office should undertake a review in depth of the communications problem and report to the SSG.

3. Number of probes

Three miniprobes have been talked of as a magic number. However, they are quite heavy, and, in a weight crunch, it would be attractive to consider a reduction from three to two. What loss of science capability would be involved? Are there circumstances under which 4 or more miniprobes might be valuable?

Action: Sub-committee discussion.

4. Entry problems

Unit construction of probe and heat shield saves weight and complexity, but probably increases interface problems which are already severe. What are the trade-offs? Is it correct to assume that a parachute is impractical from weight considerations?

Action: Ames Project Office to brief the sub-committee on the engineering and cost problems of separation. The sub-committee will review candidate instrumentation with and without the heat shield.

5. Candidate instruments

What is the complete list of candidate instruments? What are the priorities? Upon what factors are these priorities conditional?

The candidate list is probably:

Temperature
Pressure
Solar intensity
Nephelometer
Transponder
Magnetometer
Surface approach.

Action: Sub-committee discussion after details on individual instruments have been considered.

Individual instruments

1. Temperature

Technical questions:

What fully proven equipment exists?
Is there a preferred principle (e.g. resistance thermometer, thermistor, etc.)?
Environmental problems?
Probe interface problems?
Is redundancy necessary?
Inflight calibration?
What special considerations arise from the differ... between mini and maxi probes?
Will a single sensor suffice?
Time lag?

Action: Al Sieff to take a first shot at the answers.

Scientific questions:

As a function of altitude and time
What accuracy is required?
Frequency of data?
Data compression?

Action: Richard Goody and Project Office. (*)

2. Pressure

The questions are virtually identical to those for temperature.

Action: The same.

3. Solar intensity and nephelometer

Scientific problems:

Are both instruments necessary?
How serious is the restriction to day time only for the solar intensity?
Dynamic range?
Data rate?

Action: Sub-committee discussion.

Technical problems:

What instruments now exist and under what conditions have they been used on Earth?
Interface with spacecraft (with and without heat shield)?
Window condensation?
Other environmental problems?
Suggested configurations?
Weight and power estimates?

Action: Jaques Blamont in consultation Jim Weinman.

4. Transponder

Scientific problems:

Can Doppler shift be distinguished from changing refractive index?
How to combine Doppler and long base line interferometry?
How necessary is a fly-by for the LBI?
What are the communications requirements?

Action: Gordon Pettengill.

Technical problems:

Weight and power?
State of development?

Action: Arvydas Kliore and Ames Project Office.

5. Surface approach

Scientific problems:

Is it necessary?

Action: Sub-committee discussion.

Technical problems:

Weight? Power?
Interface?
State of development?

Action: Ames Project Office. *

6. Magnetometer

Venus: Strategy for Exploration states that "high priority is contingent upon further feasibility studies." These studies have still to be made and consequently the rationalization for this instrument is well behind other parts of the mission.

Scientific questions:

Under what conditions can data be analyzed in terms of internal magnetic fields?
What conditions must be placed upon the space craft and the flight path?
Must the instrument transmit from the ground?
Can it operate from a magnetic space craft?
Weight, power, data rate?

Action: Chris Russell to produce a paper and obtain reviews from Don Anderson and George Wetherill.

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